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MEAN WIND PROFILES BY WEATHER SITUATIONS

A Contribution to Stratified Climatology

18 December 1961



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MEAN WIND PROFILES BY WEATHER SITUATIONS
A CONTRIBUTION TO STRATIFIED CLIMATOLOGY

BY

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ABSTRACT

The dependence of the wind profile upon the weather situation has been investigated in this report. The weather situation has been defined using a local parameter, namely the mean stream flow within layers of the lower troposphere.

It could be demonstrated that the stratification of the wind data by the defined weather situation displays distinct differences in the mean direction profiles and the median speed profiles below 14-20 km, while above 20 km there appears little difference for the wind profiles by weather type.

The total wind error of the missile shot can be considerably reduced for some of the weather situations compared to the average condition, other situations, however, show more scatter and point towards unfavorable wind influence upon the missile shot.

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LIST OF SYMBOLS

n_i	Class Frequency
n_r	Number of Classes for Major Run
n_8	Frequency in Class 8
N	Total Frequency
p	Portion of Total N
s_z	Scale Reference point (equation 3)
x	Variable (wind direction in 16 point scale)
α	Fraction of the Departure of ϕ_m from + 0.5
$\Delta\sigma$	Difference Between σ_{15} and σ_{30}
ϵ	Error Correction
σ^2	Variance
σ_ϕ	Standard Deviation for Frequency Distribution of ϕ
σ_ϕ^2	Variance for Frequency Distribution of ϕ
σ_{15}	Standard Deviation, Classification 1500/3000 m
σ_{30}	Standard Deviation, Classification 3000/5000 m
ϕ_i	Class Code (scale)
ϕ_m	Mean Direction (defined)
$\phi_{m,1}$	Class Limit Value for Class 1
$\phi_{m,8}$	Direction Opposite the Mean Value ϕ_m (in 16 point scale)
ϕ_s	Shifted Class Number (in code or degrees)
ϕ'_m	A Starting Mean Value for Arbitrary Selected Zero Reference Point

I. INTRODUCTION

It has become increasingly important to consider wind data for application to missile firing. There are several ways to obtain the necessary information about the wind profile. Forecasting of the wind vector in several heights may be one desirable goal and has a number of positive aspects on its side. Though a recent article by Durst and Johnson (9) discussed the fact that the sets of statistical and synoptic forecast errors are quite closely related, a good forecaster will probably give excellent data for improvement of the target hitting. Nevertheless, a poor forecaster may decrease the chances considerably. Numerical forecasting tools may be available but in case of war, communications may fail or be very difficult to establish. Present state of numerical prediction success and limitations have again been discussed in a very recent article by Bergeron (3).

It is felt that climatology as the basis of statistical forecast can serve as a medium between excellent and poor forecast and in its stratified form it may closely approach the score of a skilled forecaster. Besides this, by preparation of the climatological summaries we are able to give an estimate of the possible error for the chosen method of a selected stratification parameter or class interval. Normally those error parameters are not available in employing a forecaster. Even objective forecast techniques other than by stratified climatology may not have ready available that important information for the designer.

This report investigates, therefore, the stratification of climatological wind data by weather situation and the possibility of reducing the general wind error upon target hitting. As a pilot station, Washington, (D. C.) was chosen.

II. WIND PROFILES BY WEATHER SITUATIONS

A. Definition of the Weather Situation and General Survey

First a suitable classification for weather situations must be selected. Systems like the "Grosswetterlagenkalender" for Middle Europe (15) are practically not available in the United States. Establishment of a similar system, though desirable, would have consumed too much preparatory work.

An alternative would be to employ various kinds of indices, for instance, low and high indices as computed in the Extended Forecast Section of the U. S. Weather Bureau. Future work is planned on this. One disadvantage may be found in that this index is not easily available, mainly in times of war. It also covers mostly half hemispheric areas. Thus the areal characteristics may be too extended to describe local weather events precisely.

The author decided to start the investigation by examination of a local parameter, which characterizes in some way the mean flow pattern over a local area. From this local parameter it is intended to enlarge the classification by consideration of neighbouring stations and finally end with parameters of classifying larger scale weather patterns. The detailed investigation on this problem has commenced.

As a first attempt to characterize the local flow pattern the wind direction at the station was employed. Sixteen points of the compass^{*)} may be considered as sufficient subdivision. Such the mean flow pattern as a replacement for weather situations is characterized by the wind direction at two selected height levels (entrance levels).

Three combinations had been studied in details. They were

- a) Wind direction in 1500 m and 3000 m
- b) Wind direction in 1500 and 5000 m
- c) Wind direction in 3000 and 5000 m

The short period of available data, though combined to seasons, made it necessary to restrict the classes in the higher (second) level to three, called sections. Thus instead of 256 classes (i.e. 16 x 16) only 48 classes have been set up. Tables 1 thru 4 show the numbers of observed values in each combination for Washington (D. C.), Silver Hill during the period 1948-1957. This station is also used later to demonstrate the mean wind profiles.

^{*)} Footnote: It is assumed that the relation between 16 points of the compass and the wind direction is so well known that no further detail is necessary.

At the beginning subdivisions by wind speed groups had been tried. It appeared that a variable windspeed would have been necessary for a balanced subdivision. This was not economical in respect to the improvement of the result. A constant wind speed value would have divided classes with westerlies only, or split the material into insufficient groups. This is not economical.

Weather situations characterized by this program therefore are based on 16 classes of wind direction in a lower level and 3 sections in the higher. The higher level sections express whether the same stream pattern holds in higher levels or whether there is a turn to the left (backing) or to the right (veering). Random variations had been taken into account by assuming no change of the flow pattern, when the higher level was different from the lower level for only ± 1 point of the 16 point wind rose. This involves a possible maximum turn of the air flow of $\pm 45^\circ$ and an average change of $\pm 22\frac{1}{2}^\circ$ when the direction in the higher level has changed one point. As the number of possible changes within the group is only a fraction of the total cases within the entire group, it is reasonable to consider this a weather situation with (practically) no change of the flow pattern between the height of the definition levels (called section 2).

Backing (section 1) was considered to comprehend directions $x - 2$ through $x - 7$, where the x is the direction of the lower level in 16 points and the figure is the number of classes in 16 points. Veering (section 3) combines the remaining cases $x + 2$ through $x + 8$. Thus we assume a minimum shift of $\pm 45^\circ$ with height.

This subdivision of flow patterns into sections in the higher levels has some physical background in the relation to cold and warm air advection. It is known that by the thermal wind relation the (geostrophic) wind backs with height for cold advection and veers with height for warm advection. Although this result is rigorously valid for geostrophic winds only, we may quantitatively relate it to the sections used in our classification scheme. Departures from the geostrophic wind in the lower layers between 1500 and 5000 m may be negligible and the division into sections may thus be connected with cold and warm advection for the selected sections 1 and 3 in our case.

By this kind of interpretation the sections 1, 2 and 3 would correspond to cold advection, little or no advection and warm advection, respectively.

It is understood that the mechanism of advection is more complicated and no immediate conclusion in respect to the actual size of advection can be drawn from the data. The relation of the classifying principle by turn of the wind direction with height to the thermal wind and advection, however, was to be mentioned.

In this view Tables 1 through 4, listing merely the occurrence of the 48 classification types by 3 choices of level combinations, give some physical meaning as to frequency of warm and cold advection by wind direction of the lower levels.

Table 1 portrays the general survey for the 3 selected kinds of combinations. Types with advection are more frequent in the 1500/5000 m combination, as expected. Westerly winds (direction 11-13) show the least percentage of advectioanal relation. Warm advection (section 3) is mainly connected with southerly winds (7-9), cold advection with northerly to easterly winds (16 and 1-3).

Tables 2 through 4 show the detailed structure by seasons for each of the 3 selected level combinations. Types with advection are more frequent in summer. Further details may be omitted here.

B. Resultant Wind Vector and Wind Coordinates.

Treatment of wind data in meteorology has been a problem in many respects as unlike other elements the wind is a vector quantity. Predominant is the technique to split the wind velocity into zonal and meridional components and handle those components by statistical techniques developed for one dimensional use. This manipulation leads to the bivariate distribution (14) and in its simplified form, the bivariate circular distribution. It was introduced by Brooks and Collaborators (4). In recent years Crutcher (8), Court (7) and the author (10) could show that the latter probably oversimplifies the problem and the actual distribution is more complicated.

If the wind vectors are split into components, then the bivariate distribution is a better approach than the circular distribution and highly desirable to be used. One characteristic of it is the resultant wind vector or mean vector which is based on the summation of the single components. More details see for instance Conrad and Pollak (6), Brooks (5) and others.

The author however prefers, if the problem does not particularly require a division into zonal and meridional components, to employ the natural wind coordinates, wind direction and speed. This may solve a secondary problem at the very same time. Some wind data are recorded in classes of 16 points of the compass and a split into zonal and meridional components may introduce some bias. (See also reference 13). This bias is practically eliminated by using directional classes and speed.

It is well known that the resultant wind vector by its definition will be zero if we have two direction values of 180° distance with the same wind speed. More details had been discussed very recently by the author (12). Thus, the resultant wind vector does not necessarily show close relationship to frequency occurrence.

One tool to solve these discrepancies had been published by the author in his proposal of the "polar normal" distribution (10). Another way which will be applied in this report has been discussed by the author in a preceding report (11). It defines mean value and standard deviations for wind direction without splitting the wind vector into components. Tables 5 and 6 portray the comparison between the computed resultant wind vector and the "mean wind co-ordinates" (speed, direction) for sample distributions of arbitrarily selected weather situations in summer and winter. The tables list speed and direction (converted from the components) of the resultant wind vector and for the wind coordinates the median (50%) wind speed (magnitude of vector) and mean wind (direction of vector). The latter has been defined in reference (11).

Table 7 permits an evaluation of the difference between the resultant wind vector and mean wind coordinate. It is noticeable that for weather situations other than westerly flow in 1500/3000 m (codes 10, 13) the values may considerably differ.

As could be expected, the median value for wind speed generally exceeds the speed of the resultant vector. In special cases, where extreme wind values have much influence upon the resultant wind vector, this may be reversed. It can be seen, however, that in such cases the speed of the resultant vector does not exceed the median scalar wind speed much. The negative sign in the differences of the directions of Table 7 expresses that the direction of the resultant wind vector must be turned toward the left to obtain the mean direction of the wind coordinates.

C. General Remarks About Mean Direction and Standard Deviation by Weather Situation

After definition of the weather situation and the decision to use direction and speed rather than zonal and meridional component for the wind profiles, some survey tables may be presented first.

Tables 8 through 11 contain mean wind direction and standard deviation for selected levels by weather situation using the wind direction at 1500 and 3000 m, the latter for section 2 (no turn).

Table 8 lists the mean values for winter, Table 9 contains the summer. They demonstrate the variation of the mean value by weather situation compared to the combined data, listed in the second column. A graphical presentation of these mean profiles is given later in Figures 3 and 4 and more details are discussed in the pertinent section of this report.

Study of Tables 10 and 11, the standard deviation corresponding to Tables 8 and 9, illustrates a slight decrease of the average standard deviation (two last columns) compared to the total data, given in the second column. Only the levels between 8 and 18 km, where some increase appears, seem to be exceptions. We notice, however, that in these levels also weather situations exist, for which the value of the combined data is undercut. This result indicates that by stratification of the data into weather situations the scatter may be far less than for the average condition. Some weather situations exist, however, for which the scatter is larger. The latter are conditions when missile firing must expect less accuracy in target hitting.

By glimpsing over Tables 8 through 11, improvement of the scatter does not seem to be too successful. One point may be stressed, however. Figures 1 and 2 permit an evaluation of the range within which we would expect 68% of the frequency. The graphs represent the mean wind direction and the range $\pm \sigma$ (the standard deviation) as the abscissa ($= 68\%$ frequency) with the weather situation as the ordinate. These scatter areas are shown for all selected levels from surface through 30 km. The shaded area indicates the part, when the 68% range of the total data and the one for the weather situation coincide. We recognize, mainly in summer, that situations from North through South over East have not much in common in the lower layers.

This would mean, e.g. we would expect 68% of the frequency to fall between 180 and 360 degrees. Meanwhile for easterly winds in 1500 m with no turn up to 3000 m we observe 68% of the frequency between 0 and 180 degrees. An obvious failure of the missile shot in this case would be no surprise, if we use the unstratified material. Thus, although at first thought the scatter may not appear to be reduced, target hitting can be improved by the stratification in eliminating obvious failures. This in effect reduces the scatter area indirectly.

Figures 1 and 2 may also serve to illustrate graphically which of the weather conditions display less scatter than the total (combined) data.

Tables 12 through 15 resemble Tables 8 through 11, except that they present results for the division using the wind direction at 3000 and 5000 m as characteristics for weather situations. Again, comparison of mean value and standard deviation for the total data against the weather situation shows differences in mean value and standard deviation. The mean profiles differ slightly from the computed values for 1500/3000 (see later detailed discussions). This is to be expected as the selection of the material into groups is different.

We may be interested to judge which of these sets of weather subdivisions is better in respect to the scatter of the directional values. This we may study in building

$$\Delta\sigma = \sigma_{15} - \sigma_{30}$$

where $\Delta\sigma$ is the difference of the standard deviation, the σ_{15} and σ_{30} are the standard deviations for the specific weather types at selected levels from surface through 30 km with index 15 for wind direction classification 1500/3000 m and 30 for wind direction classification 3000/5000 m. Any minus value in the $\Delta\sigma$ therefore tells that the σ_{15} is smaller than the σ_{30} and vice versa for positive signs.

The result is presented in Table 16. First we may notice that the combination of the total material (total data of section 2) does practically not differ in winter except for the 30 km level. The number of cases, however, is below 25 in 30 km. This is not sufficient for the -9 degree difference to be significant. The same is valid for 30 km in summer. The other part of the column "total data of section 2" shows in summer somewhat smaller scatter between 8 - 18 km and more scatter at the surface for the 3000/5000 m classification type. This can be explained. In moving the selection parameter (entrance level) to higher altitudes we expect an improvement of the relation in the adjacent layers, but a loosening in layers which move farther away like the surface.

The average scatter difference $\Delta\sigma$ in the last column of Table 16 indicates which scatter is less, σ_{15} or σ_{30} . For the purpose of this comparison the adjusted average has been employed to eliminate somewhat the bias of gaps in the material.

We notice that in general the σ_{30} is slightly less than σ_{15} except for the surface level. This latter fact has the same reason as mentioned above.

We may check whether this tendency of positive $\Delta\sigma$ in the average is merely an effect of some extreme values which overpower smaller departures of the other sign. Thus, we count the signs and find for winter 44 plus and 23 minus (and 4 zero) in the 8 km through 30 km levels and 9 minus and 2 plus at the surface. These figures are more than random, tested at the 95 percent significant level. The corresponding numbers for the summer tables are 69 plus, 30 minus, (6 zero) for 8 through 30 km and 14 minus and 2 plus for the surface, also statistically significant.

Thus, by judgement of the directional aspect, the classification of the weather situation by directional values between 3000 and 5000 m may have some slight advantage above the 1500/3000 m types because the general scatter is less than in the latter.

This question, however, cannot be completely answered in this connection, as the various levels enter the computation of target scatter with different weight.

Further studies are in progress which concentrate on a detailed investigation of the problem to develop an optimum stratification parameter. They use the wind profile in a modified way in order to increase the economy of the investigation.

D. Mean Wind Direction Profiles

1) Scatter area and computation of the mean direction value.

It has been suggested by the author (12) that instead of the meridional and zonal components with subsequent bivariate circular distribution or bivariate distribution, we may use wind coordinates. This changes the scatter area from a circle (or ellipse) into a segment of a circle of which the limits are the two direction values as radial lines and two speed values as pieces of a circle. Those segments may be selected from the (empirical) frequency distribution to assure close agreement with the desired expectation of probability in practice. They also could be selected by statistical theoretical consideration if desired.

For missile firing the integral effect of the scatter areas between surface and top height (limits bound to the missile type) must be taken. It should be emphasized here that by subdivision into the proposed weather situation levels between 1500 and 3000 m or 3000 and 5000 m have virtually no scatter area. This may be explained as follows.

By definition there must be one class of the wind direction in the lower entrance level of the 16 classes of weather types, while in the level above 3 sections are selected. Thus 100 percent of the frequency in the lower level must fall within a class interval of $22\frac{1}{2}$ degrees, which corresponds to a standard deviation of less than 7° . Though in section 2 of the higher level the condition had been expanded to include ± 1 point of the 16 point wind rose, the standard deviation will be approximately 10° , which is very low. Higher values would be expected for a turn of the wind direction in the upper level (section 1 and 3), however, Table 1 demonstrates that those cases are not too frequent. They can also be classified as conditions unfavorable for missile firing with the corresponding consequences. Further details are explained in a later section of this report. Thus the subdivision into weather situations can accomplish a remarkable reduction of the scatter throughout major portions of the altitude range. In this range we have to take into account the scatter of speed values only. Herewith the selection parameter to characterize the weather situation serves simultaneously to reduce the scatter area.

The procedure to compute the mean value $\bar{\theta}$ has been thoroughly discussed by the author (11). By this technique $\bar{\theta}_m$ mean directions in close agreement to the mode can be computed. It has also been mentioned, that for particular data more economical methods than those proposed in that report may be used. From the wind profiles for Washington, D. C., Silver Hill (period 1948-1957), which are presented later in this report, approximately 85% proved to be unimodal after stratification by weather situation. For unimodal distributions it is not necessary to compute the entire cycle of the proposed scheme to determine the $\bar{\theta}_m$. We may use the following abbreviated method.

From the author's theoretical discussion in the pertinent report (11) we see that the main concern for nonsymmetrical distributions is the effect of classes which change the sign of approaching the true mean value. If we obtain a starting solution for an arbitrary selected reference point of the periodic scale, then

$$N\phi_m = \pm (N\phi'_m - 16 \sum_{8+\phi'_m}^{\phi'_m} n_i) \quad (1)$$

This is the modified equation for 16 classes in our case. Here the ϕ_m is the true mean value, the N the total frequency, the ϕ'_m a starting value obtained for an arbitrary selected reference point of the periodic scale and the last term the n_i represents the class frequency. Notice that the summation of the n_i starts at the class number 8 opposite the arbitrary selected reference point (for 16 class intervals).

Thus the first problem is to find the zero point of the scale as close to the mean, in order that there may be no shift. We recognize also, if the class frequency for classes to be shifted is zero, then the computed value ϕ'_m would be immediately the mean ϕ_m .

To solve this first problem, we may employ the runs of classes with zero class frequency. A run is defined as the number of consecutive classes with this specification, namely, zero class frequency. If this run contains more classes than half the class number of the periodic scale, then the size ϕ'_m represents already the ϕ_m . The second term on the right side of equation (1) will then be zero.

In selecting the scale reference point (s_z), we may follow the same method as outlined for the second group discussed below, but the computed value ϕ'_m represents already the mean, namely

$$\phi'_m = \frac{\sum n_i \phi_i}{N} \quad (2)$$

where the ϕ_i denotes the class code (scale). This resembles exactly the non-periodic case.

In the second group we may modify the runs of classes with zero frequency by including classes with a frequency of less than a portion p of the total N . For 16 classes used in this investigation the $p = 5\%$ proved to be sufficient. Thus, we list the run with the number of classes with less than 5% of N .

This serves simultaneously to obtain a survey of bimodal or multimodal cases. Distributions with one major run can be classified as unimodal. In practice, bimodal cases with one major run can also be treated similarly and may be included. Bimodal cases with runs of approximately the same length and multimodal cases may be separated and placed into group three.

After having determined the runs, which is a matter of seconds, we may locate the zero point of the scale at the middle class of the remaining classes with frequency above 5% of N.

Thus the scale reference point s_z rounded to whole units falls into the class

$$s_z = \frac{16 - n_r}{2} \quad (3)$$

where n_r denotes the number of classes for the major run. It is immaterial, at which side of the distribution we start counting or which direction we turn around the scale.

After placing the reference point of the scale, s_z , and identifying this class with the scale code 0, we can proceed with numbering the adjacent class + 1, 2...etc., in the one direction and -1, -2...etc., in the opposite direction. Then we compute ϕ'_m by formula (2), where the ϕ_1 denotes the code value. This gives a first approximation of the mean value. In some cases this approximation will suffice.

Exact computation can be obtained by shifting the reference point so many whole class units as indicated by ϕ'_m . If $\phi'_m = 2.2$, we would shift 2 units; if $\phi'_m = -2.6$, we would shift 3 units towards the negative direction. This shift does not require a renumbering of the classes and recomputation by equation (2). It requires merely a correction accomplished by equation (1), namely

$$\phi_m = +(\phi'_m - \phi_s) - \frac{16}{N} \sum_{\phi_s}^{8+\phi'_m} n_i \quad (1a)$$

where the ϕ_s denotes the whole class number shifted (in code or degrees, depending on the units used). ϕ'_m and ϕ_s would be used with their respective signs. This should bring the ϕ_m to be less than |0.5|. If this is not accomplished, an additional class shift is necessary.

Now we may discuss the utilization of the class opposite to the ϕ_m . If the true $\phi_m = 0$, then halving of the class with code 8 would be adequate. If the true $\phi_m = +0.5$, then this class would be fully included into the positive side, if $\phi_m = -0.5$, then it should be entirely included into the negative side. Proportioning would be necessary for values of ϕ_m between the outlined limits. Assume, the $\phi_m = -0.5$ and we have used the class 8 with the plus sign instead of the required minus sign. The correction for this error derived from equation (1) would be

$$\phi_m = \phi_{m_8} - \epsilon = \phi_{m_8} - \frac{16}{N} n_8 \quad (1b)$$

where the n_8 denotes the frequency in the class 8. This ϵ tends towards zero as ϕ_{m_8} goes to +0.5. Thus we may express the correction by $\alpha\epsilon$, where the α is a function of the departure of ϕ_m from +0.5.

$$\phi_m = \phi_{m_8} - \alpha\epsilon = \phi_{m_8} - \alpha \frac{16}{N} n_8 \quad (1c)$$

Theoretically this α with limits between 0 and 1 should be expressed by an infinite series, composed of the first correction, the second correction, etc., until the proportioning of the class 8 has taken the value required by

$$\alpha = 0.5 - \phi_{m_1} \quad (4)$$

whereby the ϕ_{m_1} is the limit value.

Although theoretically the α should be expressed by this series, in practice the α may be approached by one correction term, replacing the ϕ_{m_1} by ϕ_{m_8} , which is the computed value from equation (1a). The

convergence of the correction series can be shown and can also be deduced by reasoning.

Thus the final ϕ_m after application of equation (1a) may be

$$\phi_m = \phi_{m_8} - (0.5 - \phi_{m_8}) \frac{16 n_8}{N} \quad (5)$$

The ϕ_{m_8} represents the value obtained by equation (1a), disposing of the positive sign for class 8.

As a brief summary we may repeat:

(1) In group one with one run of $n_z \geq 8$ classes with zero frequency the ϕ_m can be determined like in the nonperiodic case.

(2) For group two with a run $n_z < 8$, whereby now the n_z includes class frequencies less than 5% N, we determine the major run (biggest number of consecutive classes). Then the reference point is placed at

the class interval $s_z = \frac{16 - n_r}{2}$ (equation 3), counted from any side of

the remaining classes. Then determine $\phi_m = \frac{\sum n_i \phi_i}{N}$ by equation (2). Shift classes, until $\phi_m < |0.5|$. The shift is computed by use of equation (1a). Consider the effect of the class opposite to the class in which now the ϕ_m falls after shifting by equation (5).

(3) Bimodal and multimodal cases, if they do not show one major run considerably different from the other, should be treated as outlined in the earlier report (reference 11).

From the available material at Washington (DC) Silver Hill, 40% fell into group one, 15% into group three. From the remainder in group two, 47% needed no shift, 47% a shift of 1 class interval and 6% a shift of two class intervals. Thus the ϕ_m could be computed very rapidly.

A numerical example, taken for Washington, D. C. in summer demonstrates the method.

Example 1

Weather Situation 01
section 1 level 8 km

Class ϕ_i	Frequency n_i	$n_i \cdot \phi_i$
8	0	0
7	1	7
6	1	6
5	0	0
4	0	0
3	0	0
2	1	2
1	6	6
0	10	0
-1	9	-9
-2	6	-12
-3	5	-15
-4	0	0
-5	2	-10
-6	0	0
-7	0	0
Σ	41	-25
ϕ'_m		-.61

Shift -1

$$\phi_m = (-.61 + 1.00) + \frac{16}{N} \cdot 0$$

$$= .39$$

Hence the new ϕ (= class 7 before stays positive.⁸

$$\text{Prorated: } \phi_m = .39 - (0.50 - 0.39) \cdot \frac{16}{41} \cdot 1$$

$$= .39 - 0.04 = .35$$

Thus for the original numbering of ϕ_i the true mean value would be -.65

Example 2

Weather Situation 02
section 1 level 8 km

Frequency n_i	$n_i \cdot \phi_i$
1	8
1	7
0	0
0	0
0	0
0	0
2	4
2	2
4	0
6	-6
3	-6
3	-9
0	0
1	-5
0	0
0	0
Σ	23
	-5
	-.22

Originally no shift, but ϕ_8 will be prorated

$$\phi_m = -.22 (0.50 + 0.22) \frac{16}{23} \cdot 1 = -.22$$

$$-.50 = -.72$$

now a shift is necessary

$$\phi_m = (-.22 + 1.00) - \frac{16}{23} \cdot 1 = .08$$

Now we prorate again

$$\phi_m = .08 - (0.50 - 0.08) \frac{16}{23} \cdot 1 = -.20$$

Thus for the original numbering of ϕ_i the true mean value is -1.20

The two solutions -.65 and -1.20 could now be converted into a 360 degree scale, depending on the value $\phi_i = 0$ and the class interval of $22\frac{1}{2}$ degrees.

2) Mean Wind Direction Profiles 1500/3000 m.

By the technique described in the previous section a climatological study of mean wind profiles for Washington, D. C. (Silver Hill) with observations of the period 1948-1957 has been performed.

We may present mean directional profiles by weather situations in 8 graphs, Figures 3 through 10.

Mean direction profiles for weather situations defined by the wind direction at 1500 and 3000 m are introduced first.

Figure 3 illustrates the mean direction profiles in summer. We notice a wide dispersion in the troposphere and lower stratosphere (below 20 km) with a transition zone between 14 and 20 km and evidently a bundling above 20 km with easterly winds. This confirms the expectancy that the selected weather types are connected with different profile types. Upper stratospheric circulation appears to have only loose connection to the lower troposphere, if there is any relation at all assumed. This means above 20 km practically no influence of the weather situation is visible and we probably would not obtain different types of mean profiles by utilizing a selection parameter above 20 km.

The influence of the surface friction layer (Ekman Spiral) is clearly expressed by the turn to the right from surface to 1500 m. A left turn appears, when easterly winds prevail in 1500 and 3000 m. Lettau (16, 17), however, could show that this may be an effect of the different thermal structure. This may concern the situations with easterly winds above the friction layer. This explains the contradiction to the general right turn theory by the Ekman Spiral which is valid for the westerly winds. The small or left turn exposed in the graph supports Lettau's findings.

It is interesting to note the tendency for the wind profile to turn back to West if northeasterly wind components occur at 1500/3000 m, while for southeasterly winds the profile remains South through 14 km, then enters the transition zone between 14-20 km with East winds above 20 km. The profiles for South winds between 1500 and 3000 m have been repeated on the left side of the graph for better reading.

The computed mean value 90° at 10 km for the profile with East wind between 1500-3000 m does not follow the general smooth pattern. It is caused by insufficient data and may not be significant. The author did not want to smooth it because no precise decision could be made whether the 30° in 8 km or the 90° in 10 km would be wrong.

We proceed in the discussion with Figure 4, the mean direction profiles in winter. Again we notice differences between the profiles of the selected weather situation, but the differences are not quite so drastic. This appears so, as westerly winds prevail from surface

throughout 30 km and no profiles are encountered between Northeast and South. For the latter the wind direction in summer remains easterly to southerly above the classification level through 14 km.

More dispersion is visible in the upper stratosphere (above 20 km) than in summer. This is not necessarily an effect to point toward more dependence of the upper stratosphere upon low level weather situations. The variation ranges within 60 degrees and may merely express that the circulation pattern shows more disturbances on upper air maps between 100 mb and 10 mb in winter than in summer.

Figure 5 supplements the wind direction profiles in summer for situations where the wind between 1500 and 3000 m backs (section 1) or veers (section 3). The relatively strong bundling between 8 km and 30 km is remarkable. In general, the profiles follow closely the shape connected with weather situations of westerly wind directions (1500/3000 m) without turn (section 2). Though the lower part of the profiles differ, the upper part can be treated like those westerly situations.

Figure 6 accompanies Figure 4. It contains the wind direction profiles in winter, when the wind directions between 1500 and 3000 m shift. We notice the same effect as described in the summer profiles of section 1 and 3. The wind profiles follow above 8 km the type characterized by westerly winds (1500/3000 m) of section 2.

Thus we may summarize the results for the mean direction profiles classified by wind direction in 1500 and 3000 m in brief terms: All profiles differ in the first 3 km. Weather situations of section 2 (no turn between 1500 and 3000 m) show a distinct difference in the direction profiles in summer up to 20 km, in winter up to 10 km (except for the two winter profiles with northeasterly winds in 1500/3000 m, where differences reach to 14-18 km). Some dispersion is observed above 20 km in winter, while in summer a close bundling at East winds is striking.

All profiles of sections 1 and 3 follow above 3 km approximately the type of westerly winds with no turn between 1500 and 3000 m. (section 2).

3) Mean Wind Direction Profiles 3000/5000 m.

Mean wind direction profiles for weather situations defined by the wind direction at 3000 and 5000 m are presented next. Figure 7 illustrates the profiles in summer for constancy of the wind direction between 3000 and 5000 m. Again, there appears a definite difference of profiles by weather type. No influence above 20 km is visible where all weather types merge to East winds. We also notice the clear cut between weather types with Northeast and Southeast winds in 3000 to 5000 m, similar to the 1500/3000 m type profiles. Southeast winds between 3000/5000 m are followed by veering, Northeast winds by backing from 8 km through 14 km. Subsequent is a transition zone between 14-20 km and above East winds prevail.

Figure 8 exhibits profiles in winter when the wind direction between 3000 and 5000 m is constant. They resemble the 1500/3000 m types presented in Figure 4. Like there, we have some dispersion above 20 km, and all types tend toward westerlies above 14 km. No profile types exist for directions 03 through 07 in 3000/5000 m. Out of line (but not erroneous) is the type with Northeast winds between 3000 and 5000 m, where northerly winds resume through 20 km.

Figure 9 contains the summer profiles in which the wind direction between 3000 and 5000 m shifts. Although different in the lowest 5 km, they tend towards uniformity above 5 km with dispersion between 270 and 30 degrees from 8 km through 14 km and cone-shaped merger towards Easterly above 20 km. Thus, the similarity to the profile with Westerly winds, section 2 is not as close as in the 1500/3000 m types (figure 5).

Backing is noticeable in the surface layer for some of the profiles with Easterly directions in 3000 - 5000 m.

Figure 10 finally presents the winter profiles with shift of wind direction between 3000 and 5000 m. We recognize differences below 5 km, but bundling around West winds above that level. This resembles the result of the 1500/3000 m profiles types as discussed with Figure 6.

To summarize, the mean wind direction profiles for weather situations defined by the wind direction at 3000 and 5000 m look similar to the profiles classified by 1500/3000 m wind direction, although they do not match in all details. All profiles differ in the first 5 km. In summer individual differences between the weather situations are observed up to 20 km with easterly winds above, in winter a cone-shaped merging from 5 km to 20 km towards Westerlies can be noticed, but some dispersion is seen above 20 km.

Weather situations of sections 1 or 3 (a shift of the wind direction between 3000 and 5000 m) keep individual differences in summer up to 20 km, while in winter they resemble above 5 km the profile of West wind in 3000/5000 m of section 2.

E. Median Wind Speed Profiles.

1) General Remarks

After discussion of the mean profiles for wind direction, the wind speed must follow. Both, wind speed and direction, represent the wind vector. Again, the wind coordinates in the mentioned form may appear advantageous. The wind speed represents the total force which acts on the missile. The direction determines the angle of attack.

Frequency distributions of scalar wind speeds are not normally distributed (see references 7, 8, 10). For this reason it had been decided to evaluate wind speed profiles by the median value, which halves the frequency. Thus the presented wind speed profiles in Figures 11-18 represent values which are exceeded in 50 percent of the cases. Similar profiles can be established for any desired excess - limit.

The reader's attention should be called to one additional point. The linear line of the profiles between surface and 8 km is interpolated by connecting the speed at the surface and the value in 8 km. Correctly we should have obtained the median values for 1500, 3000, 5000 m, etc. Checking processes resulted in very little difference between the actual observed median value and the linear interpolation between surface and 8 km for the above mentioned levels. Hence, it had been decided to save the extensive work of computing median wind speed values for the entrance levels.

The median profiles illustrated in Figures 11-18 serve the purpose of a general survey. This goal is achieved by the selected altitude levels used in this program. It may be advisable to reconstruct more detailed speed profiles by utilizing 1 km levels. This necessity contrasts with the mean direction profiles. The latter obviously can be based on far less selected levels.

In this connection it should also be emphasized that the sharp corners in the median speed profiles between 10 and 14 would be smoothed into curved lines if more levels between 10 and 14 km were used. This remark will not be repeated every time in the detailed discussion of the profiles.

2) Median Speed Profiles for 1500/3000 m.

Figures 11 through 14 contain the median wind profiles for weather situations defined by the wind direction in 1500 and 3000 m and correspond to the wind direction profiles of Figures 3 through 6.

Figure 11 exhibits median profiles for the scalar wind speed (magnitude of wind vector) in summer and section 2, when the direction remains constant between 1500 and 3000 m, equivalent to Figure 3. We observe as the general tendency for all median profiles of Figure 11 an increase of the speed with maximum values between 10-14 km, a minimum of the speed between 18-20 km and a slight increase towards 30 km. Individual median profiles show between one another considerable differences in speed values. Thus, a maximum dispersion appears between 10-14 km altitude which decreases toward 20 km. From there on the dispersion remains constant towards higher altitudes. The result for the median speed profiles confirms again the difference in the profiles by weather type which had been derived by analysis of the direction profiles. In Figure 11 the median profiles for northwesterly winds in 1500-3000 m have ostensibly the highest speed of all profiles between 10-14 km. It should be repeated, however, that no additional information between 10 and 14 km has been made available for detailed plotting and a definite decision, which median speed profile will presumably have the maximum value of all cannot finally be made here.

Very weak wind speeds are revealed for weather situations of northeasterly and easterly direction between 1500 and 3000 m.

The difference between the profiles amounts to 16 m/sec in 14 km in the extreme case.

The displayed differences in the median speed profiles are expected. It is well known that westerly winds in the upper air data possess a higher speed in the average than easterly or southerly winds. Thus the wind speed profile depends partly on the prevailing wind direction. This varies within the profiles as can be seen from the discussion of the directional profiles.

We shall later see, however, that profiles with westerly winds are not necessarily bound to show the highest median wind speed.

Figure 12 illustrates the median wind speed profiles in winter and is related to Figure 4. The first glance verifies the validity of the general features described for the summer profiles, namely increase of the speed with height to a maximum at 10 km, a minimum at 20 km and slight increase toward higher altitude. There is a remarkable difference, however, to the summer profile. The maximum value is now 48 m/sec at 10 km compared to 24 m/sec in summer. The profile for weather types of westerly and west-southwesterly winds between 1500 and 3000 m displays highest speeds. Differences between extreme wind speed profiles amount

to 34 m/sec and 30 m/sec in 10 km and 14 km, respectively. This expresses that, evidently, target hitting can be considerably improved by accounting for those immense differences between weather types.

Figure 13 corresponds to Figure 5 and supplements Figure 11 with median wind speed profiles for the summer of weather situations when the direction between 1500 and 3000 m turns (sections 1 and 3). Smaller differences than in Figure 11 are found between the individual profiles but are still visible below 14 km. This agrees with the finding in directional profiles where also little contrast between the individual type occurs.

Figure 14 demonstrates the median wind speed profiles in winter for the situations where the wind direction between 1500 and 3000 m shifts. As in the related Figure 6 of the direction profiles the variety of profiles is also not great. The profile of weather type southeasterly winds with veering between 1500 and 3000 m appears with the maximum median speed. The prevailing winds between 8-14 km are southwesterly winds for this type, while for other weather types westerly winds dominate. The higher median speed value for the weather type southeast indicates that the frequency selection used in this type of combination (sections 1 and 3) may contain weaker winds in westerly, but stronger winds in southwesterly winds than in the average. This would explain that the southeasterly weather type exceeds the other types in the median wind speed, contrary to the general expectation.

In addition to the mentioned effect of the restricted number of levels, the number of observations is around 10 and not too much confidence can be given to the particular plotted value. The magnitude looks reasonable, but more data may reduce the numerical value. Then the westerly groups would dominate, which would agree with the expectancy.

We may summarize some of the important features of the speed profiles. From a surface value the median speed is increasing towards a height between 10-14 km with a decrease above towards a minimum at 18-20 km. Above 20 km the median speed increases again slightly.

Summer profiles show almost half the amount of median speed as the winter. Therefore, the elimination of the wind bias is more important in winter months. The variety of the individual median profiles by weather types is greatest for weather situations with no turn of the wind direction between 1500 and 3000 m and displays a maximum scatter between 10-14 km.

The stratification of the material by defined weather situations now selecting segments from the total wind vector frequency distribution, can contribute to the reduction of the scatter area.

Figures 15 through 18 portray the median wind speed profiles for weather situations defined by the wind direction at 3000 and 5000 m height. They show much similarity to the profiles of Figures 11 through 14, although there are departures in some details.

Figure 15 illustrates the median speed profiles in summer of section 2, when the wind direction remains constant from 3000 through 5000 m and corresponds to the direction profiles of Figure 7. The dispersion shown in the graph from 8 km through 20 km may be explained by the variation of the mean direction profiles. The bundling above 20 km is related to the prevailing easterlies above that level. The departure from the average displayed in 26 km for the profile with SE and SW directions between 3000 and 5000 m may not be significant.

Figure 16 exhibits the median speed profiles in winter for weather situations with no turn between the defining (entrance) levels and corresponds to Figure 8. Similar to the 1500/3000 m median speed profiles, more dispersion than in summer is visible between surface and 20 km.

The range between profiles with maximum and minimum median speed is 33 m/sec in 10 km and 30 m/sec in 14 km altitude. The low value of the median speed profiles for southerly directions between 3000 and 5000 m is quite noticeable.

Figures 17 and 18 supplement the median profiles for summer and winter with the weather situations of section 1 and 3 and correspond to Figures 9 and 10, the mean direction profiles. They follow the general tendency and will not be discussed here.

F. Tables of Frequency Distribution by Selected Class Intervals

1) Frequency Tables for Wind Direction

The average direction profiles or median speed profiles must be accompanied by their respective scatter range. For this reason tables like Tables 17-20 have been developed. The complete set of tables is too voluminous and will be submitted separately^{*)}. The following set of tables is planned, given under example of Tables 17 through 20. They list the result for Washington, D. C. (Silver Hill) in summer (June through August) for a 10 year period (1948-1957).

The first 3 tables (17 through 19) deal with the wind direction profiles. The particular example represents the weather situation when the wind direction at 1500 m has been East (entrance level). This weather type has been chosen as all three sections are encountered. The 3 sections have been identified in the discussion of the definition of the weather type and divide the material into 3 groups, namely, when east winds remain from 1500 through 3000 m (section 2), are backing (section 1), or veering (section 3).

The tables contain the observed percentage frequency for pre-determined ranges (class intervals). There are 3 sets of tabulations planned.

Table 17 is a selected example of a set, where the reference angle ϕ'_m of the frequency distribution of wind directions at a given altitude is based on the wind direction of the entrance level. Thus the value listed under this column headed by ϕ'_m indicates the average turn angle of the wind in reference to the wind direction at the entrance level. A negative sign denotes a turn counter-clockwise (to the left).

The second set of tables (an example is shown in Table 18) is based on the actual wind direction ϕ_m . This has been adopted for comparison of the frequency distributions in respect to their departures from normality.

The last set of tables (portrayed in Table 19) uses also ϕ_m as reference point. The columns in the predetermined ranges, however, furnish the wind direction in the actual wind scale of 360° , starting at North and turning clockwise.

^{*)} Footnote: The set of tables would amount to 96 tables for direction values and 32 for wind speed for each classification type, that is 1500/3000 and 3000/5000. Hence, there are 256 tables.

The ϕ_m or ϕ'_m denote the reference points at each altitude for the frequency distributions. The column headed by σ_ϕ lists the standard deviation, computed by the formula

$$\sigma^2 = \frac{\sum (\phi_i - \phi_m)^2}{N - 1} \quad (1)$$

where the restriction exists, that the $|\phi_i - \phi_m| \leq 180^\circ$.

The predetermined class intervals had been selected by technical requirements. Thus the adjoining classes to the mean value ϕ_m or ϕ'_m list the range for $\pm 18^\circ$ of the empirical data. For example, for the 8 km altitude and section 2, we learn from Tables 17-19 that $\pm 18^\circ$ of the empirical material, that is 36% of the data falls into a range of -95.6 through -24.0 degrees departures to the entrance level (Table 17). This means 36% of the material shows a turn to the left (counter-clockwise) between 24.0 and 95.6 degrees.

We may further conclude that the same 36% of the data lie within 354.4 and 66.0 degrees (actual wind coordinates, Table 19); and the $\pm 18^\circ$ of empirical data cover a distance of 38.9 degrees, the -18° of 32.7 degrees from the mean angle ϕ_m (Table 18).

The frequency range 15.9% and 84.1% represent 68.2% of the data and correspond to the one-sigma (=standard deviation) range of the normal frequency distribution, the limits 2.28% and 97.72% including 95.44% of the data are equivalent to the two-sigma range of a normal distribution, the columns 0.135% and 99.865% would be identical with the three-sigma range of a normal distribution.

The column headed "range" lists the extreme range of the total frequency distributions which does not necessarily enclose the whole circle. The column "n" shows the number of observational data in the frequency distribution at the altitude level. Sometimes numerical values in the tables are given in parenthesis or are replaced by a dash for the following reason.

Suppose we have a nonperiodic scale. In a symmetrical frequency distribution the mean occurs at the center. If the distribution is asymmetric, the mean may be displaced toward one end.

In the establishment of the columns headed by the selected frequency counts (as in Tables 17-19), we begin the count at the mean. Thus in a symmetric frequency distribution we have left the 2.28% when we encounter 47.72% progressing from the mean towards the end. No observation may be available if the distribution is asymmetric. Then we cannot compute any value for the 0.135% column. It may even happen that data are insufficient to obtain a numerical value for 2.28%.

(column 1). Similar considerations are valid for the upper limits 97.72°/° and 99.865°/°.

In a periodic scale, we find no "end" in the sense of the nonperiodic scale. Thus we may continue to compute the 0.135°/°, etc. value. It must exist, as we ever have 100°/° of the observations. This leads to the formality that we even can progress through class intervals without frequency until we finally find an occupied class, of which we take the frequency needed. Naturally, this is unreasonable. It would compare to the process in the nonperiodic scale of completing the lack of data on one side of the distribution from the other side.

Hence the rule was adopted that progress through empty classes ends the distribution if reasonably the periodic scale may be converted into the case of a nonperiodic scale with both ends. Then the result under the pertinent columns was given in parenthesis, if the number of observations was not sufficient to meet the frequency requirement (i.e. if less than 47.72°/° of the observations progressing from the mean value were available for the 2.28°/° limit, etc) and a dash indicates that no observation was available from the last listed class interval to the desired range.

2) Frequency Tables for Wind Speed

The frequency distribution of wind direction by weather type is aided by frequency tables of wind speed similar to Tables 17-19. An example is illustrated in Table 20, in which the weather situation East wind in 1500 m in the 3 sections is presented.

The frequency distribution of the scalar wind speed does not follow a normal distribution in a linear scale. (Reference 7, 10). For this reason the 50% value (median) had been selected as reference point and the column σ (= standard deviation) which appears in Tables 17-19, has been deleted. Also cancelled are the columns 0.135% and 99.865%. The headings of all other columns correspond to the respective columns of Tables 17-19. The unit of the values is given in m/sec.

It had been decided to furnish only one set of tables for the distribution of wind direction observations, comparable to Table 19.

3) The Scatter Area

Tables 19 and 20 enable to select the scatter area which is a segment of a circle (Fig. 19). The chosen example is not a good one in respect to a small scatter area.

If we would be interested in the one-sigma limits of the wind profile at 8 km for section 2, the empirical scatter area shown in Table 19 would be limited by the angles of 256 and 89 degrees (a range of 193 degrees) and by speed bounds (Table 20) of 4.7 and 18.1 m/sec (a range of 13.4 m/sec). The mean angle would be $\phi_m = 27$ degrees, the median speed 12.6 m/sec. The $\pm \sigma$ range of a total 193 degrees, evaluated from the empirical one-sigma limits is greater than the range calculated from the computed σ_ϕ , which would be 159 degrees. A comparison of the standard deviation of Table 11 would show that the chosen example of Table 19 belongs to a group which displays a large scatter area.

The $\pm 2\sigma$ range would be computed from σ_ϕ to amount to 318 degrees, but the empirical limits show a range between 284 and 176 degrees, which is 292 degrees.

If the computed σ_ϕ exceeds 60 degrees, then the three-sigma would exceed the 360 degrees, which is empirically nonexistent. Therefore, it is probably better to follow the empirical boundaries or restrict to the $\pm 2\sigma$ range. Tables 10, 11, 14 and 15 display, how often and in which layers the $\sigma_\phi > 60^\circ$.

In this connection the question of how close frequency distributions of wind directions follow a normal distribution after stratification by weather situation ought to be discussed briefly. This will follow in the next section.

G. Some Remarks on the Normal Distribution Law and the Stratified Wind Data.

1) General Remarks

As mentioned in a previous section, statistical treatment of wind data creates problems, if we desire to relate frequency distributions of wind data to the normal distribution law. It is well known that frequency distributions of the wind speed do not follow the normal distribution law. Frequency distributions of wind directions often show bimodality.

Although the normal distribution law is applied to zonal and meridional components of the wind vector, theory and observation may diverge. This has been shown by the author (10) and others.

In many reports by ABMA (1, 2, 18-22) empirical distributions have, therefore, replaced the statistical estimates.

Thus it seems logical to ask the question, how has stratification affected the distributions of direction and wind speed, although such a comparison has limitations as one station only, namely Washington, Silver Hill, has been used.

2) Frequency Distributions of Wind Directions

In a previous section it had been mentioned that 15 percent of the distributions of wind direction remained bimodal or multimodal after stratification, and 85 percent was unimodal. The latter does not imply that they are normally distributed now.

Hence, a survey had been made from the tables given as examples in Tables 17-20, how far the frequency range computed from the estimator for the standard deviation and the empirical distribution differs significantly. In these tables the empirical frequency range 2.28; 15.9; 32.0; 68.0; 84.1 and 97.72% corresponding to the theoretical ± 2.0 ; ± 1.0 and $\pm 0.5 \sigma$ has been listed. The f-test has been applied for comparison whether the empirically obtained range differs significantly at the 95 percent level from the theoretical values. The result is presented in Tables 21 and 22 for the 1500/3000 m classification.

It should be mentioned that the result is somewhat biased by identifying the mean value $\bar{\theta}_m$ with the 50 percent median value. As wind direction values follow a periodic scale, a decision had to be made at which point to start the frequency count. Hence, the above identity had been adopted, which is true for the normal distribution law. For asymmetrical distributions, however, results may be more favorable than shown here under the assumption of a different concept of reference point.

Table 21 displays for winter and summer in percentage the number of cases for the various frequency ranges in which significant departure existed. We conclude from the figure in the last column of the last line that 22 percent in winter and 17 percent in summer still differ from the theoretical value. This includes the bimodal cases, which contribute 25 percent to the winter total and 15 percent to the summer total. A clear functional relation to the height level is also visible. Between 8-14 km in winter and 8-18 km in summer departures from the normal distribution seem relatively seldom, surface and 20 km and above appear worse. The slight decline of the percentage figure to 30 m can be a result of the decreasing number of observations, which make it possible to classify a departure of a certain amount as significant in the lower layers but as nonsignificant in higher levels.

The general tendency seems to confirm the fact that the influence of the stratification decreases with distance from the stratification center and that obviously the upper stratosphere (above 20 km) is relatively independent of the stratification.

The higher percentage of departure in the surface layers was expected, as the surface layer should be complex by the multitude of influences.

Notice also the tendency for a higher likelihood of departure with increase of the frequency range. Thus the $\pm 0.5 \sigma$ comparison (i.e. 32.0 and 68.0 percent range) renders the least percentage figures.

Although this result has been derived for Washington only, it is reasonable to assume that the stratification brings frequency distributions of wind directions closer in agreement with the normal distribution law, mainly in the layers between 8 and 20 km. If the goal is to obtain a still closer agreement to the normal distribution law, then further studies are necessary.

3) Frequency Distribution for Wind Speed

In a linear scale frequency distributions of the scalar wind speed do not follow the normal distribution law. In a former article (10) the author has suggested to use a square root transformation. By this transformation the scalar wind speed distributions approximate a normal distribution.

Hence, in this report the comparison has been made for the data of Washington, D. C., Silver Hill, selecting the median value to compare with the theoretically derived by using 2σ . The standard deviation σ has been computed for the frequency distribution of scalar winds in a square scale. The result is shown in Table 22 for summer and winter. The table lists the departure in m/sec between the theoretical and the empirical value in percent of the total cases of frequency distributions. A positive value means the theoretical value is greater than the empirical value.

The Table 22 demonstrates that the median value is in 90 percent (winter) and 98 percent (summer) within ± 2 m/sec of the mean value of the square scale, thus showing excellent agreement. As should be expected, for the 95 percent frequency range, equivalent to the 2σ limit, the scatter of the departure is more. Only 33 percent of the cases in winter and 44 percent in summer stay within a limit of ± 2 m/sec. It must be considered that the scalar wind speed value, exceeded by 5 percent of the observations, is between 2 to 3 times as high as the median value. Thus logically we should also judge the departures for a higher range, namely between ± 4 m/sec. This increases the percentage values to 57 percent in winter and 83 percent in summer.

In conclusion we find that the median value is close to the mean of the squared speed. The empirical 95 percent frequency, however, diverges somehow from the theoretical 2σ value in a square root scale, mainly in winter. Further studies are necessary to evaluate the problem of the relation of the scalar wind distribution in a square root scale to the normal distribution law.

III. CONCLUSIONS

The author has demonstrated that the wind profile varies considerably, depending on the existing weather situation and that it is possible to stratify climatological data in order to reduce the wind error in missile shooting.

In this investigation the weather situation had been defined using a local parameter, namely the stream flow within a layer of the lower troposphere. This stream flow is expressed by the wind direction (in 16 points of the compass) in two levels (entrance level). This stratification compensates also somewhat for the decreasing number of observations with altitude. If there exists a bias due to weather situation, it would have appeared.

As the wind direction in the entrance level at the same time is part of the stratified material (the wind profile between surface and 30 km), its limitation to a class unit with narrow scatter reduces the total wind error within the entrance level to a minimum. The result for the other levels between surface and 30 km shows that this type of classification has practically no influence upon stratospheric data above 20 km. In the troposphere and lower stratosphere (below 20 km) the scatter area (standard deviation) is reduced for some weather situations while others display an increase compared with the unstratified data. This indicates that some situations are favorable for the reduction of the wind error while others are not. Although the stratification parameter is the wind direction only, differences in the wind speed profile for the various types also are present.

It had been mentioned that the investigation performed served as foundation to inquire the effect of stratification while the final goal would be to achieve a minimum integral wind error for the missile shot. The stratification used in this study contributes to the reduction of the wind error, but it cannot be decided whether this is the optimum reduction obtainable. Further investigations continue in this direction.

For attacking this latter problem the technique presented in this report is probably too cumbersome and some typical characteristics for the daily wind profile will be developed. This will be described in a later report.

A brief comparison between the resultant wind vector and the mean of the wind coordinates as used in this report was made. For weather situations other than Westerly flow between 1500 and 3000 m the values may differ considerably.

Before the mean wind direction profiles and median speed profiles are introduced, a short discussion on the computation of the mean direction value takes place. In it a short method of computation for particular data like the stratified wind direction data of this report

is presented which renders the mean direction value for 85% of the frequency distributions very quickly. The 15% bimodal and multimodal cases should then be treated as outlined in the earlier report (11).

The mean direction profiles 1500/3000 m and 3000/5000 m show distinct differences, depending on the weather situation. In summer this difference extends up to 20 km, while in winter above 14 km bundling is noticed. Above 20 km we have Easterly winds in summer, Westerly winds in winter for all weather situations. The Westerly winds in winter above 20 km show more divergence than the Easterlies in summer.

If the wind veers or backs from the lower entrance level (1500 or 3000 m) to the higher level (3000 m and 5000 m respectively) then the profile follows the weather situation 12 (Westerly winds without turn) above 5 km.

The median scalar speed profiles also illustrate significant differences depending on the weather situation. The general trend displays a maximum speed between 10-14 km with a decrease towards a minimum at 18-20 km. Above 20 km the median speed increases again slightly.

Summer profiles show almost half the amount of the median scalar speed as the winter. Therefore it is more important to eliminate the wind bias in winter time. In general, median wind profiles with highest scalar speeds are associated with Westerly winds while Easterly flow appears with much weaker median speed.

It can be stated, therefore, that stratification of the climatological material even with the simple device of a local classification parameter can considerably modify the integral wind error upon the missile shot. We could learn that in some weather situations better accuracy of the missile shot is attained because of a reduced scatter area, while in other situations it will be better to avoid the firing because of the unfavorable wind influence.

Although stratification was successfully applied, in this report no precise decision can be given, whether the optimum reduction of the wind error was reached. Further investigations with modified techniques, will attack this problem.

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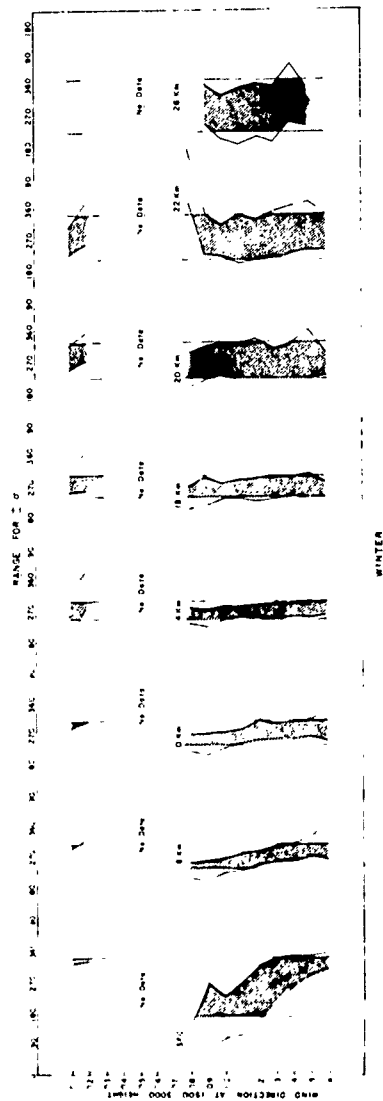


Figure 1 Area of $\pm \sigma$ range by weather situation 1500/3000 m.

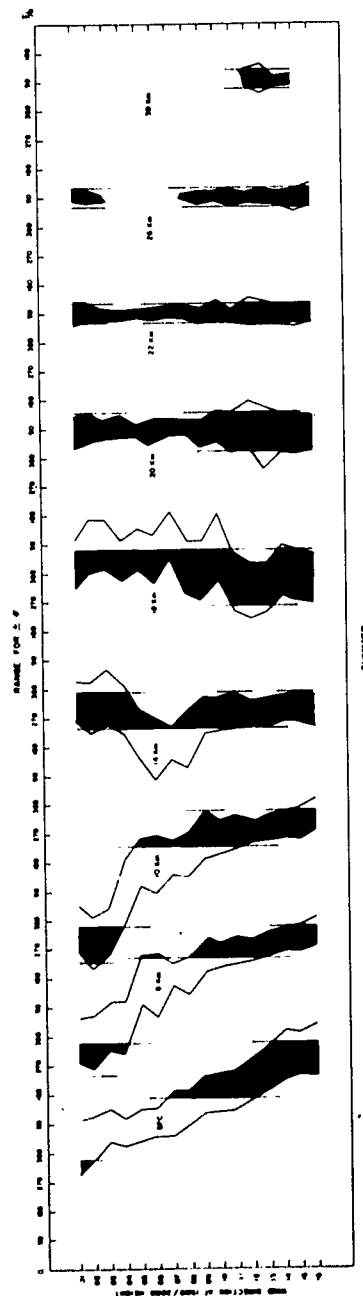


Figure 2 Area of $\pm \sigma$ range by weather situation 1500/3000 m.

Washington, D C (Silver Hill, Md)
1948-1957 (Summer Sec 2)

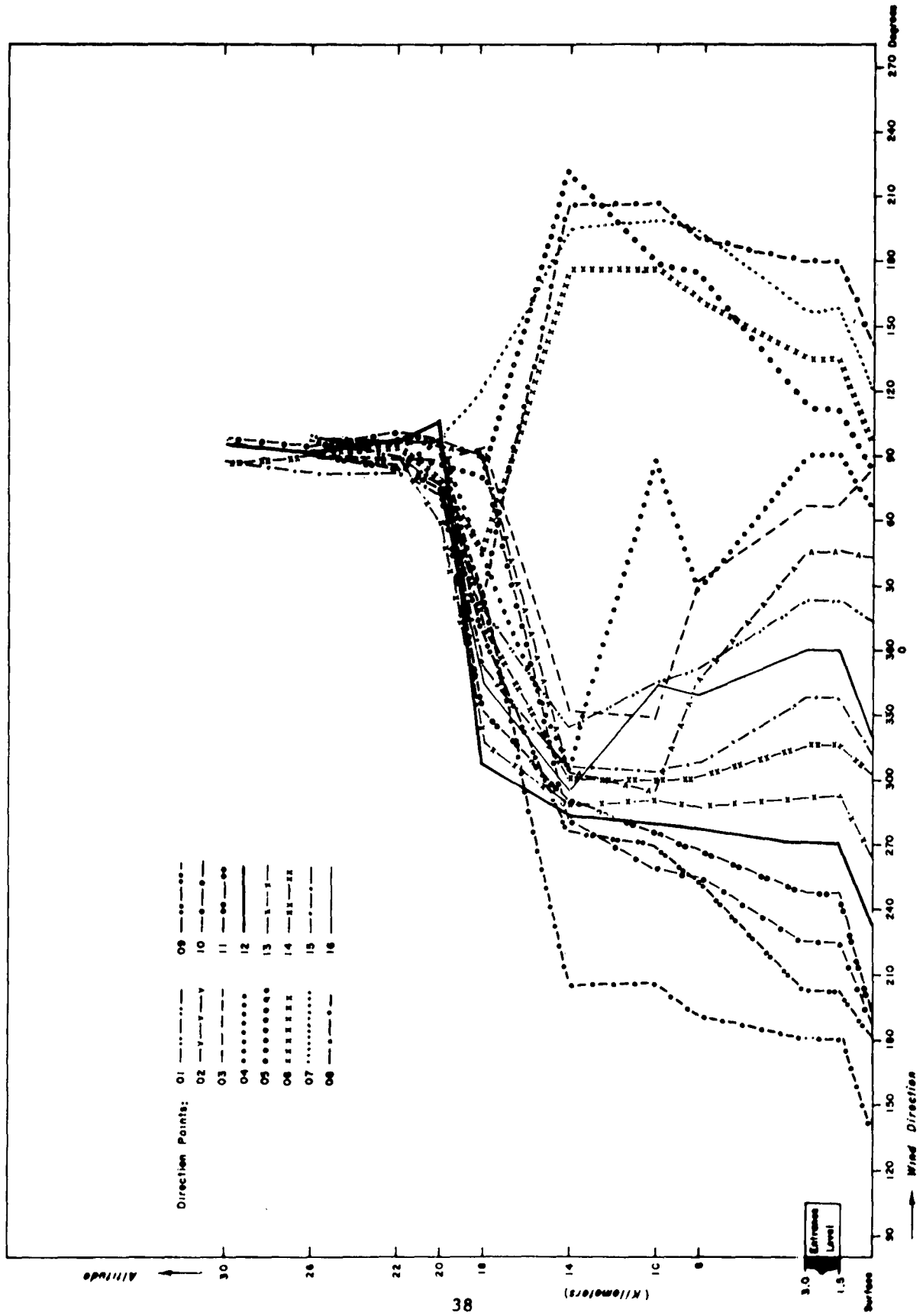


Figure 3 Mean wind direction profiles for weather situations 1500/3000, at Washington, D.C. (Silver Hill) in summer, section 2.

Washington, D.C. (Silver Hill, Md.)
1946-1957 (Winter Sec 2)

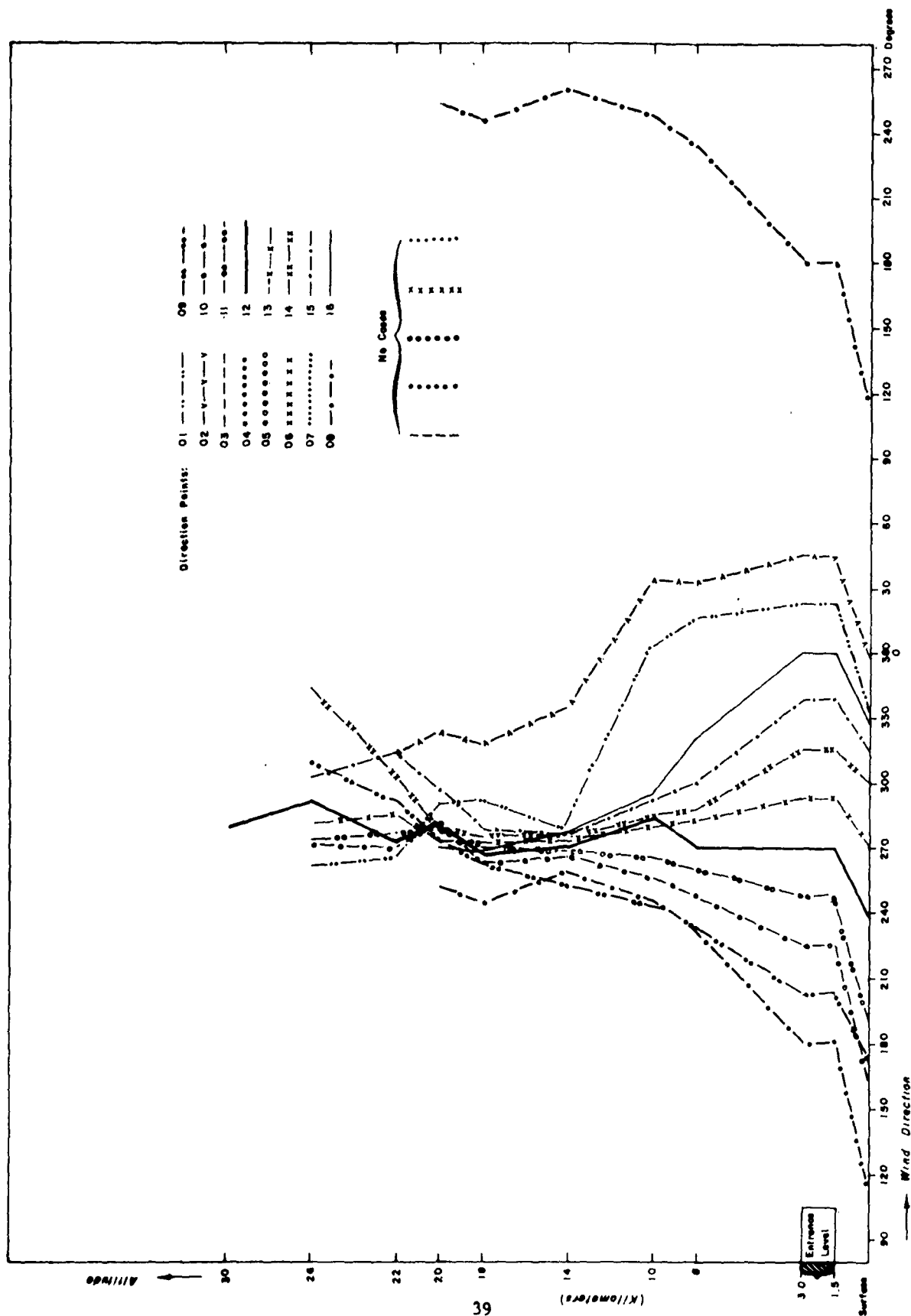


Figure 4 Mean wind direction profiles for weather situations 1500/3000, at Washington, D.C. (Silver Hill) in winter, section 2.

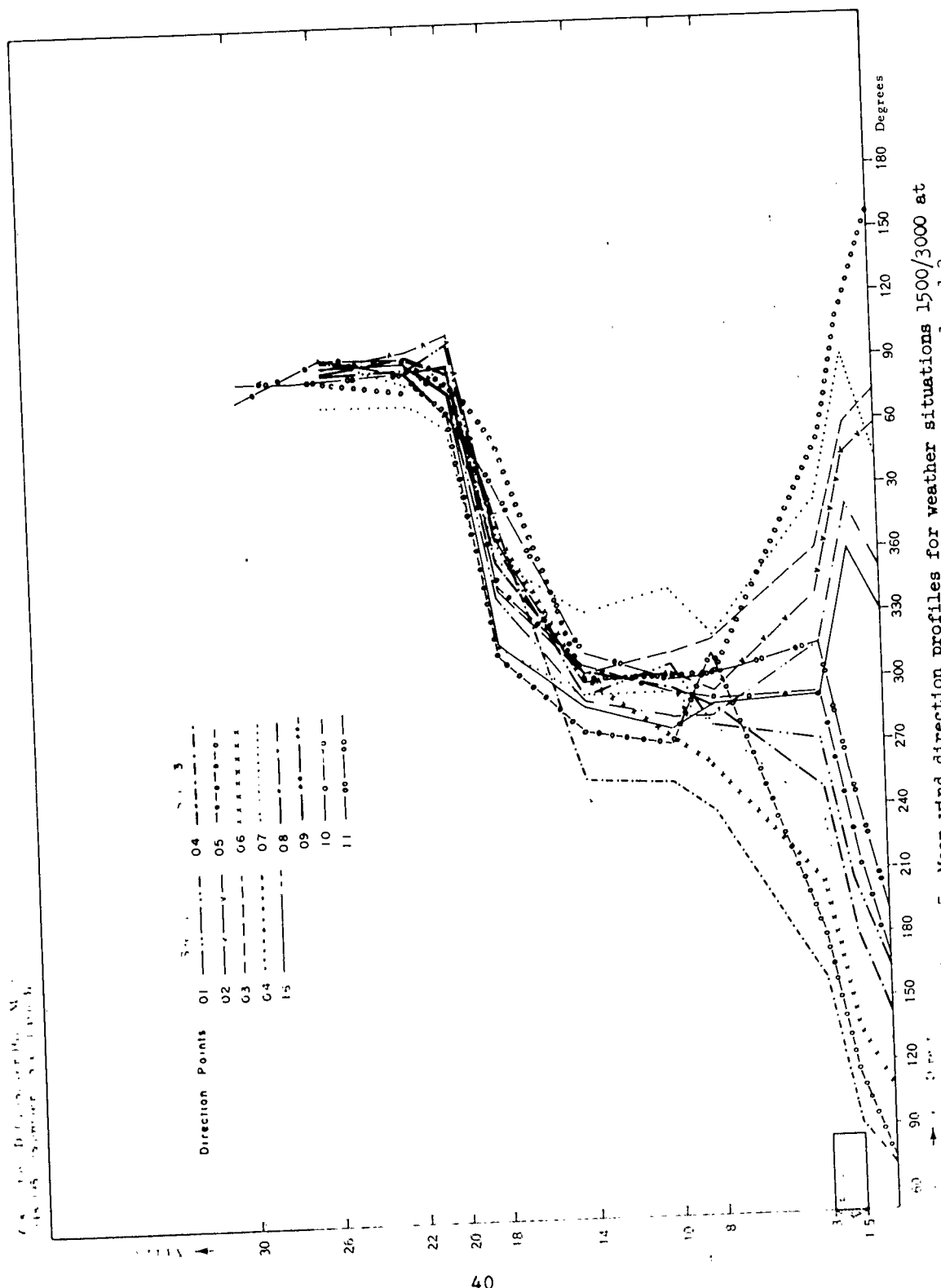


Figure 5 Mean wind direction profiles for weather situations 1500/3000 at Washington, D.C. (Silver Hill) in summer, section 1 and 3.

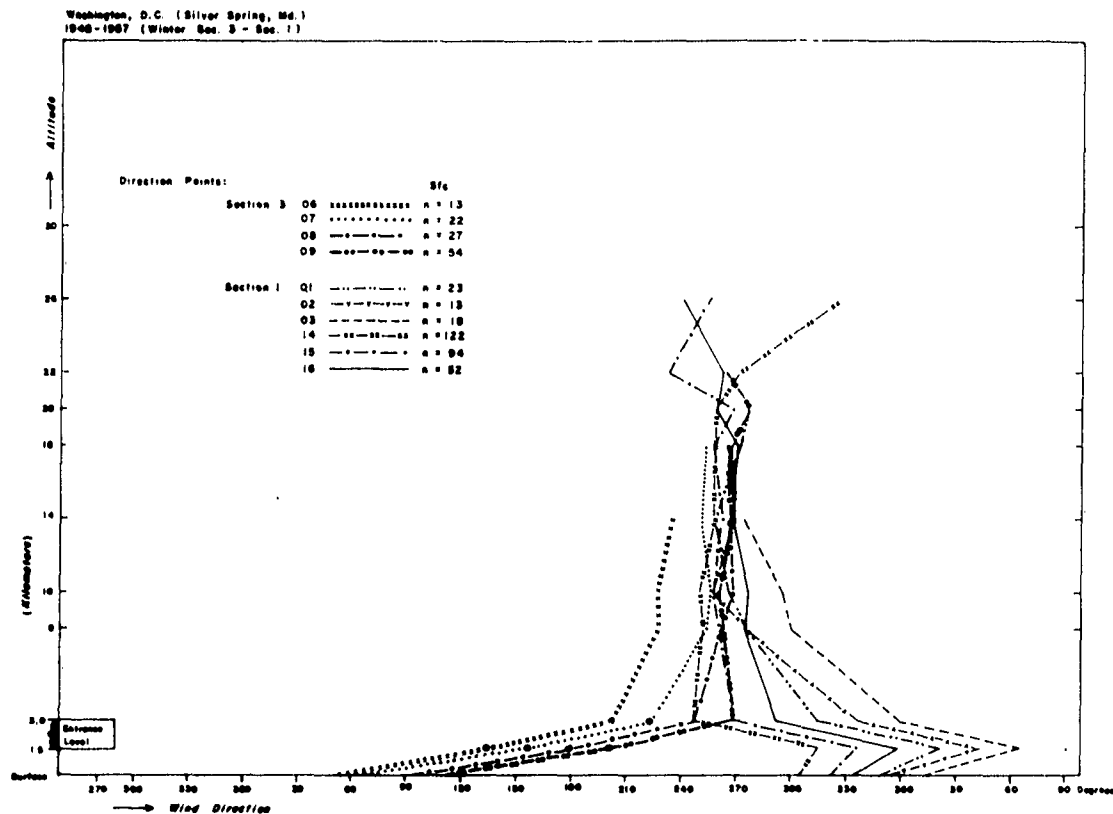


Figure 6 Mean wind direction profiles for weather situations 1500/3000 at Washington, D.C. (Silver Hill) in winter, section 1 and 3.

Washington, D.C. (Silver Hill Mt.)
1948-1957 (Summer Sec. 2)

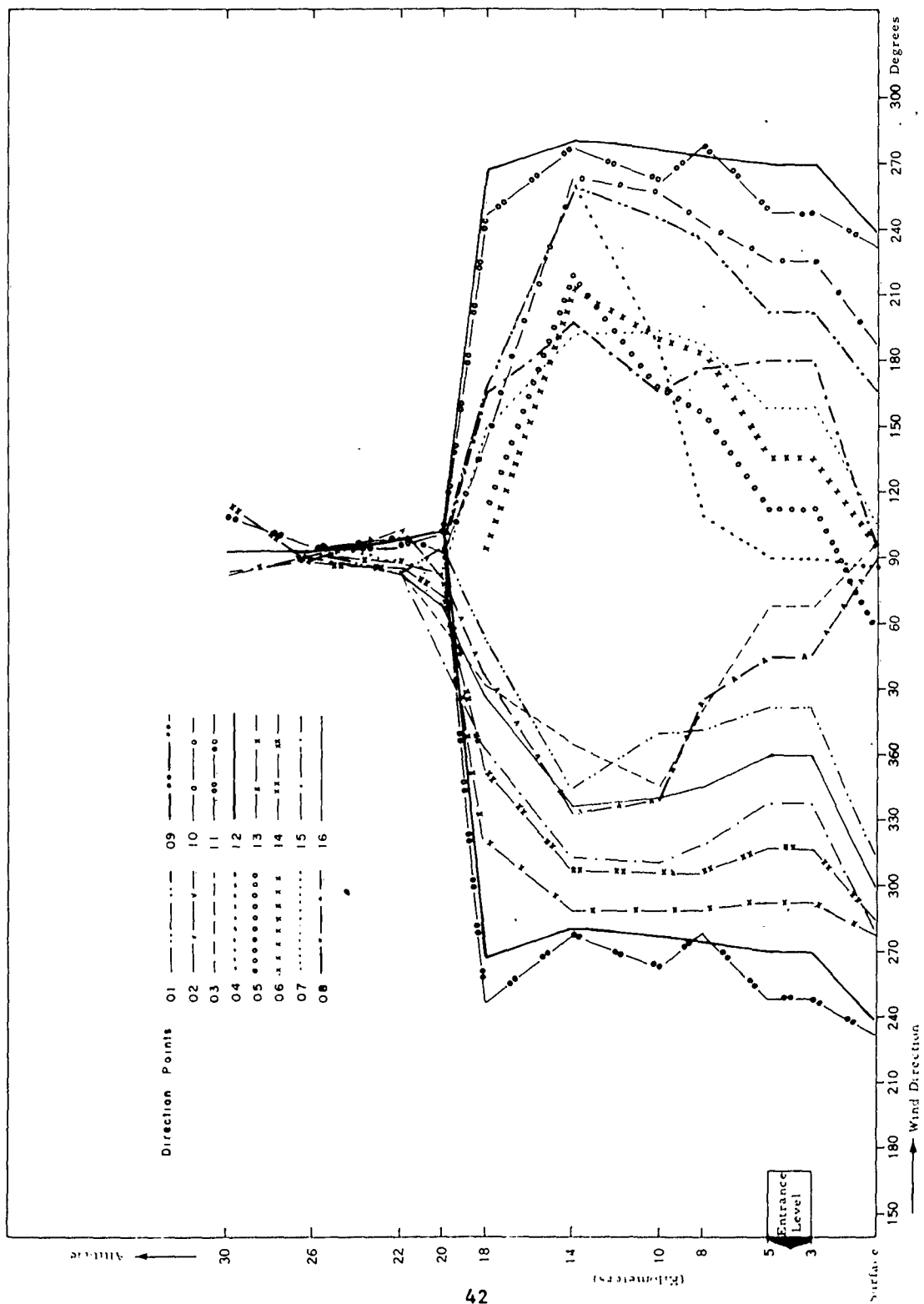


Figure 7 Mean wind direction profiles for weather situations 3000/5000 at Washington, D.C. (Silver Hill) in summer, section 2.

Washington, D.C. (Silver Hill, Md.)
1948-1957 (Winter, Sec. 2)

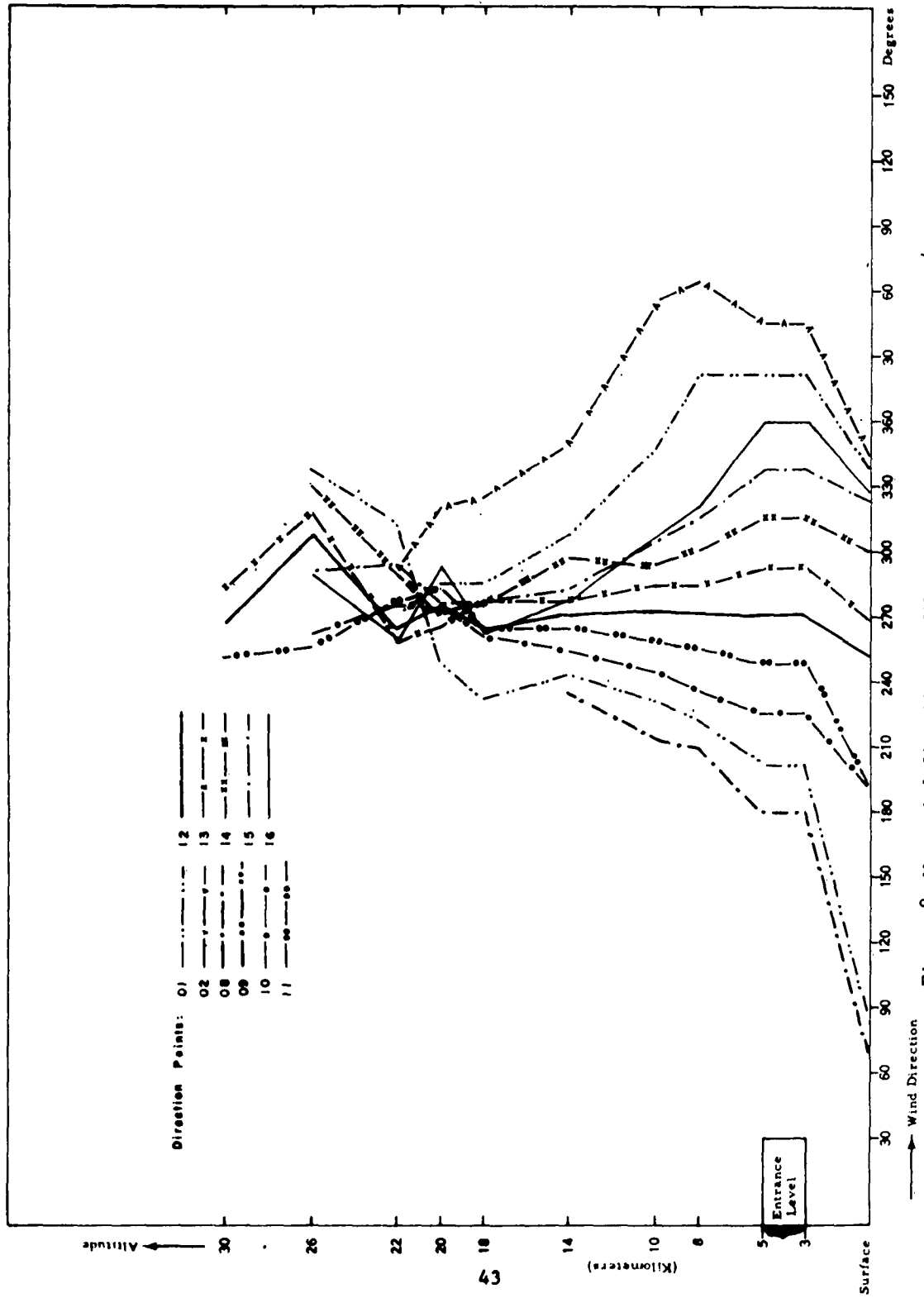


Figure 8 Mean wind direction profiles for weather situations 3000/5000 at Washington, D.C. (Silver Hill) in winter, section 2.

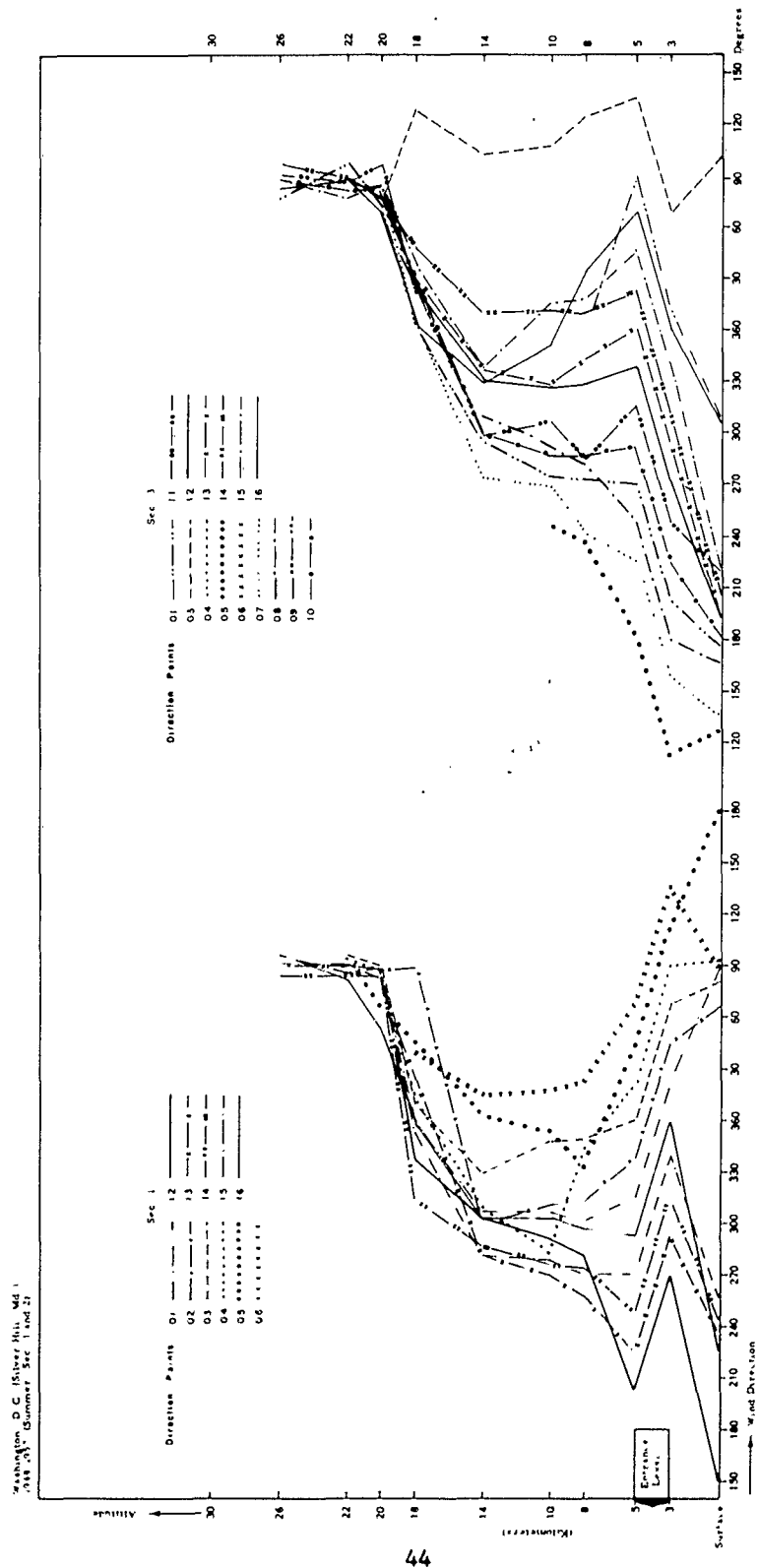


Figure 9 Mean wind direction profiles for weather situations 3000/5000 at Washington, D.C. (Silver Hill) in summer, section 1 and 3.

Washington, D.C. (Silver Hill, Md.)
1948-1957 (Winter, Sec 1 and 3)

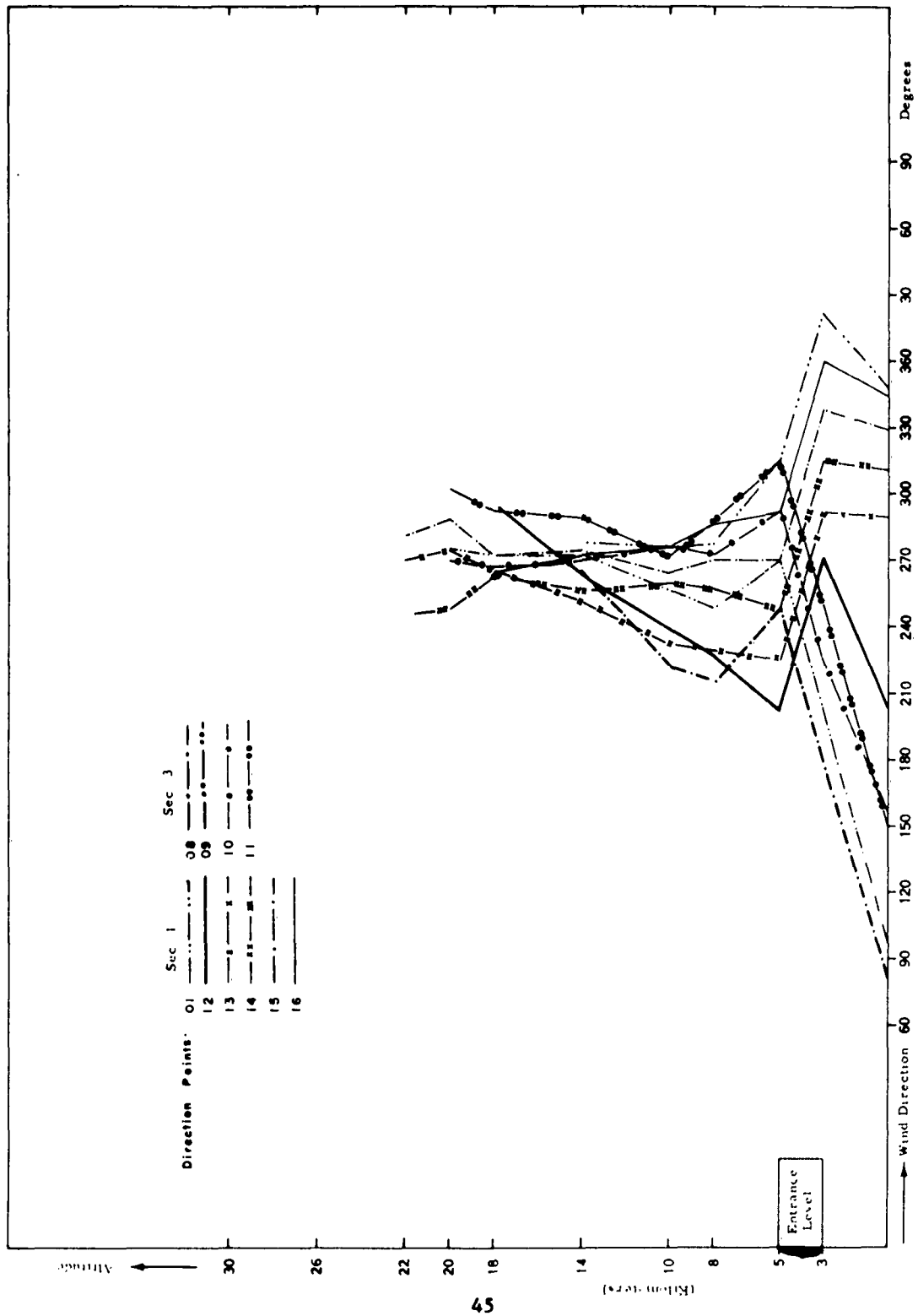


Figure 10 Mean wind direction profiles for weather situations 3000/5000 at Washington, D.C. (Silver Hill) in winter, section 1 and 3.

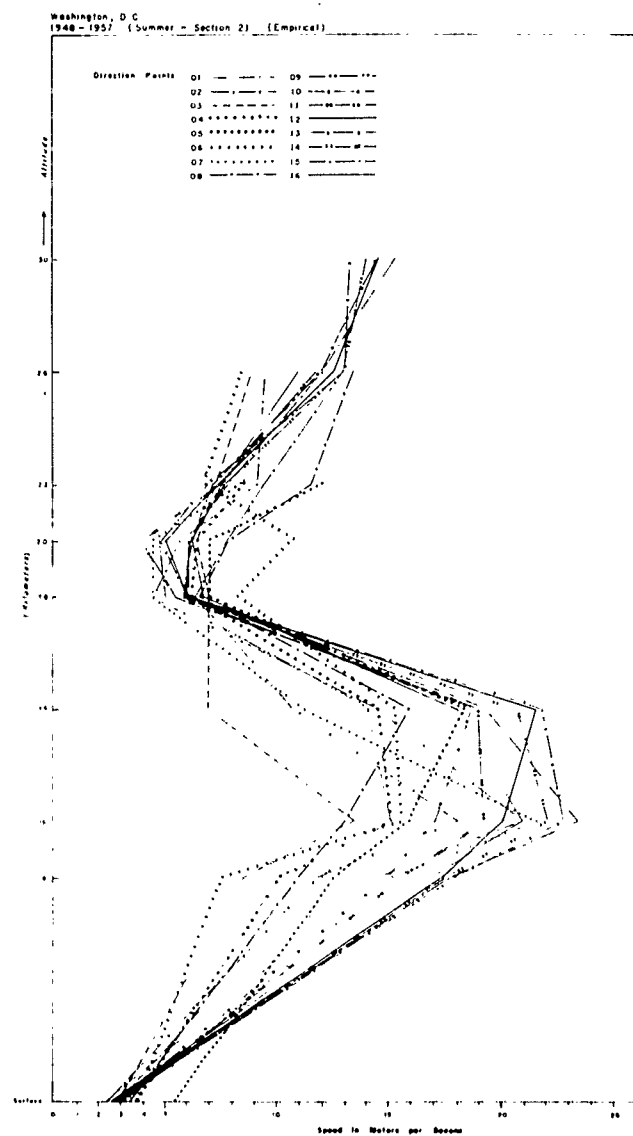


Figure 11 Median speed profiles for weather situations 1500/3000 at Washington, D.C. (Silver Hill) in summer, section 2.

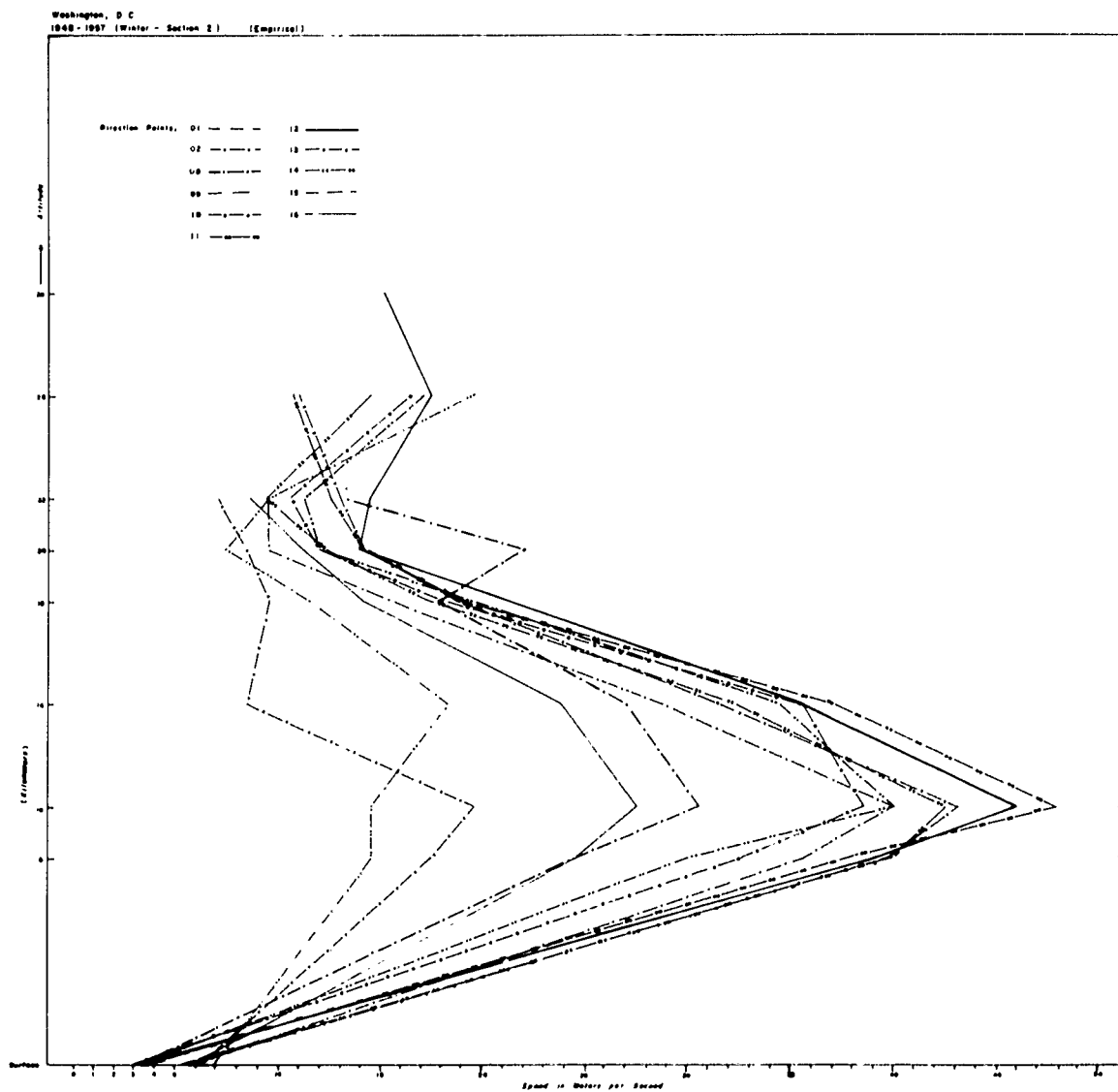


Figure 12 Median speed profiles for weather situation 1500/3000 at Washington, D.C. (Silver Hill) in winter, section 2.

Washington, D.C. (Silver Hill, Md.)
1947-1958 (Summer, Sec 1 and 3)

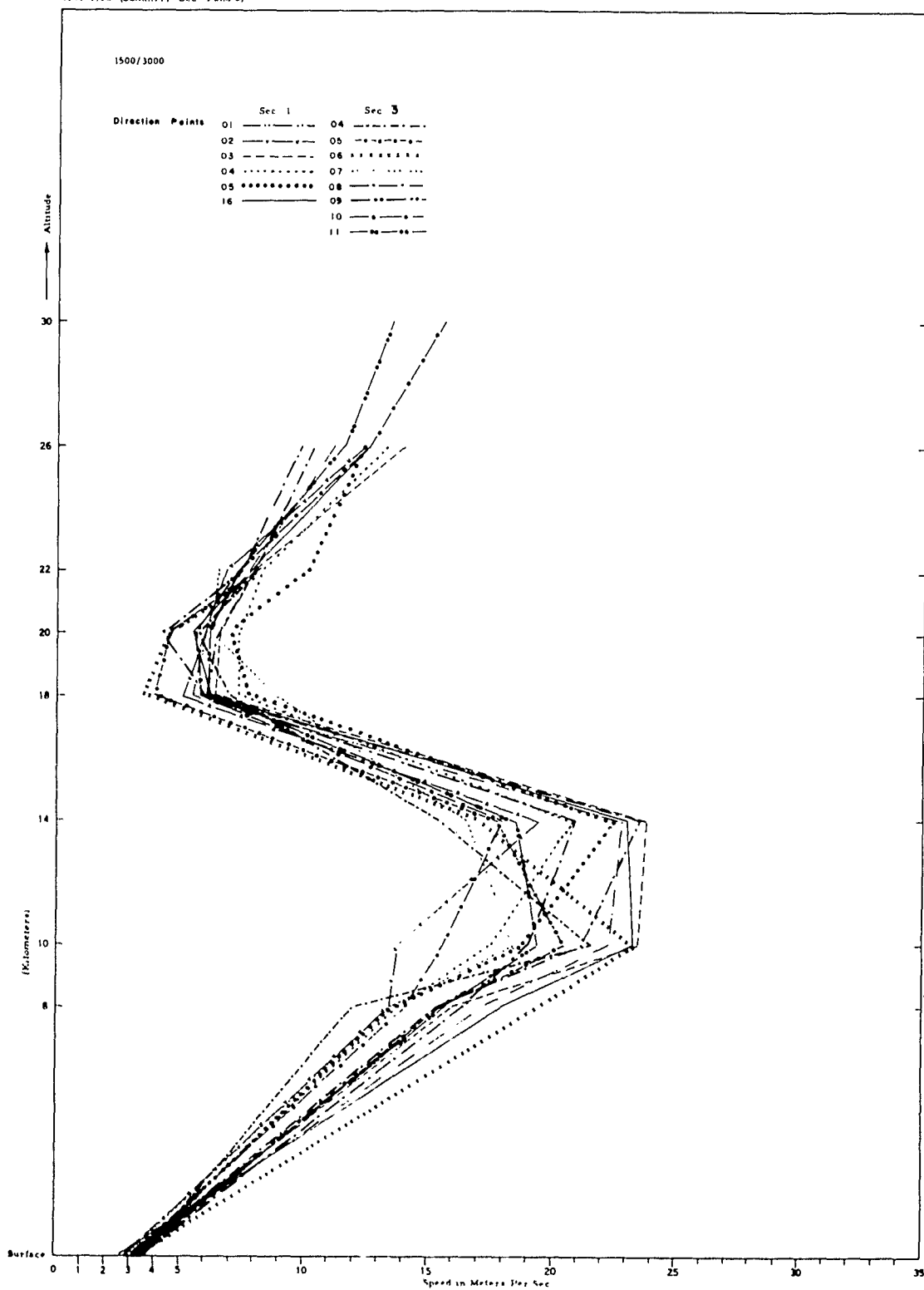


Figure 13 Median speed profiles for weather situations 1500/3000 at Washington, D.C. (Silver Hill) in summer, section 1 and 3.

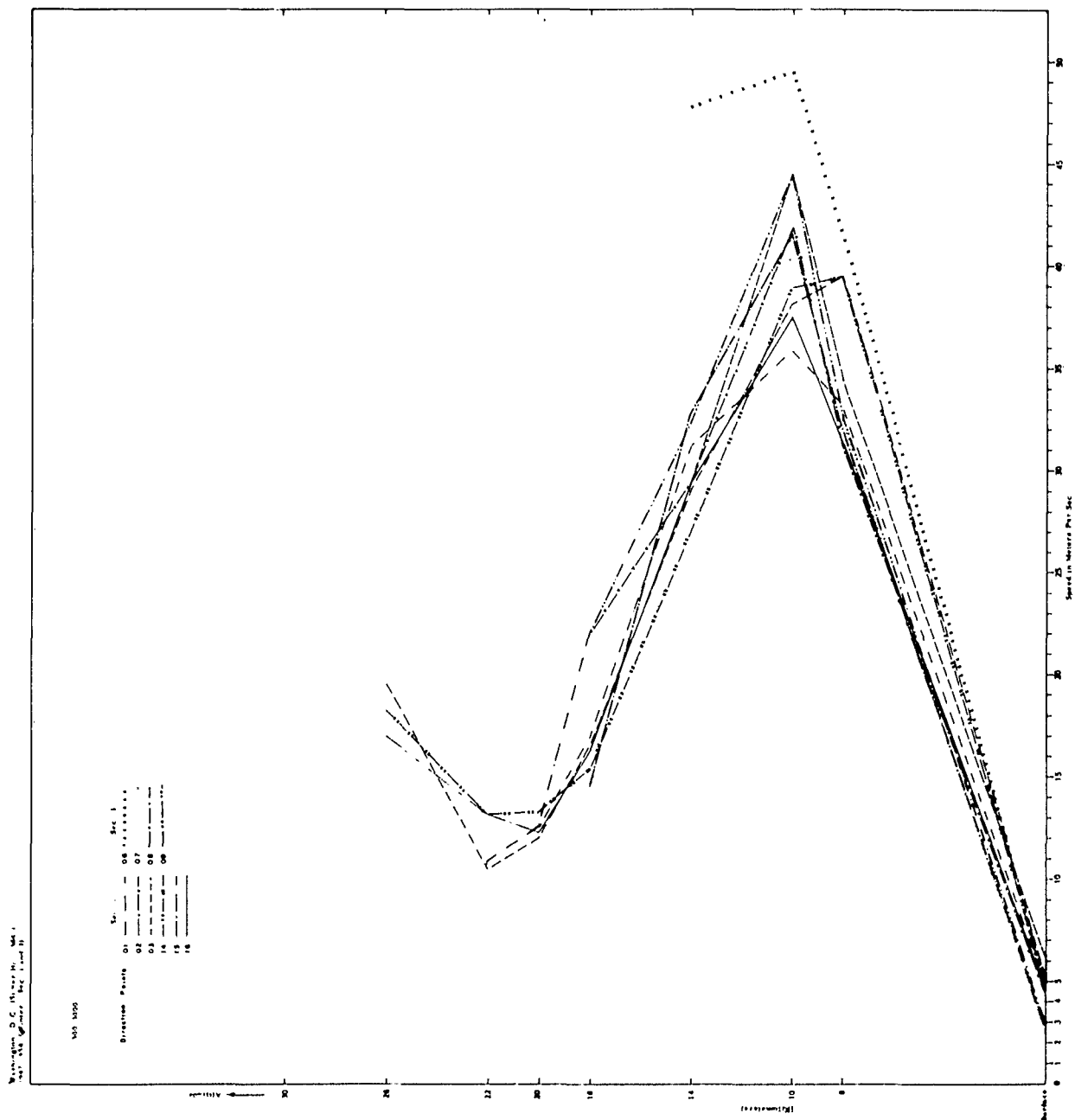


Figure 14 Median speed profiles for weather situations 1500/3000 at Washington, D.C. (Silver Hill) in winter, section 1 and 3.

Washington, D.C.
1948-1951 (Summer, Sec. 2) (Empirical)

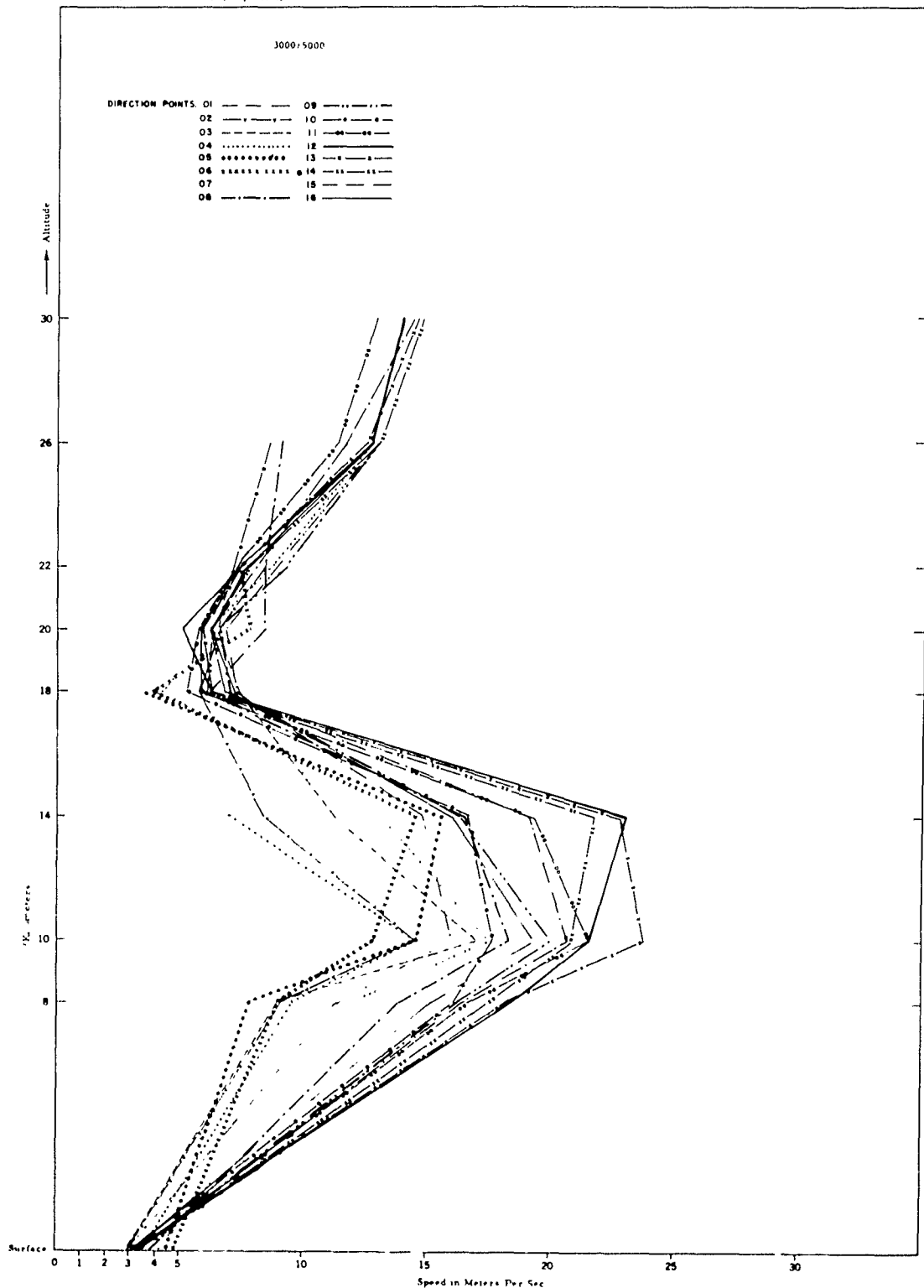


Figure 15 Median speed profiles for weather situations 3000/5000 at Washington, D.C. (Silver Hill) in summer, section 2.

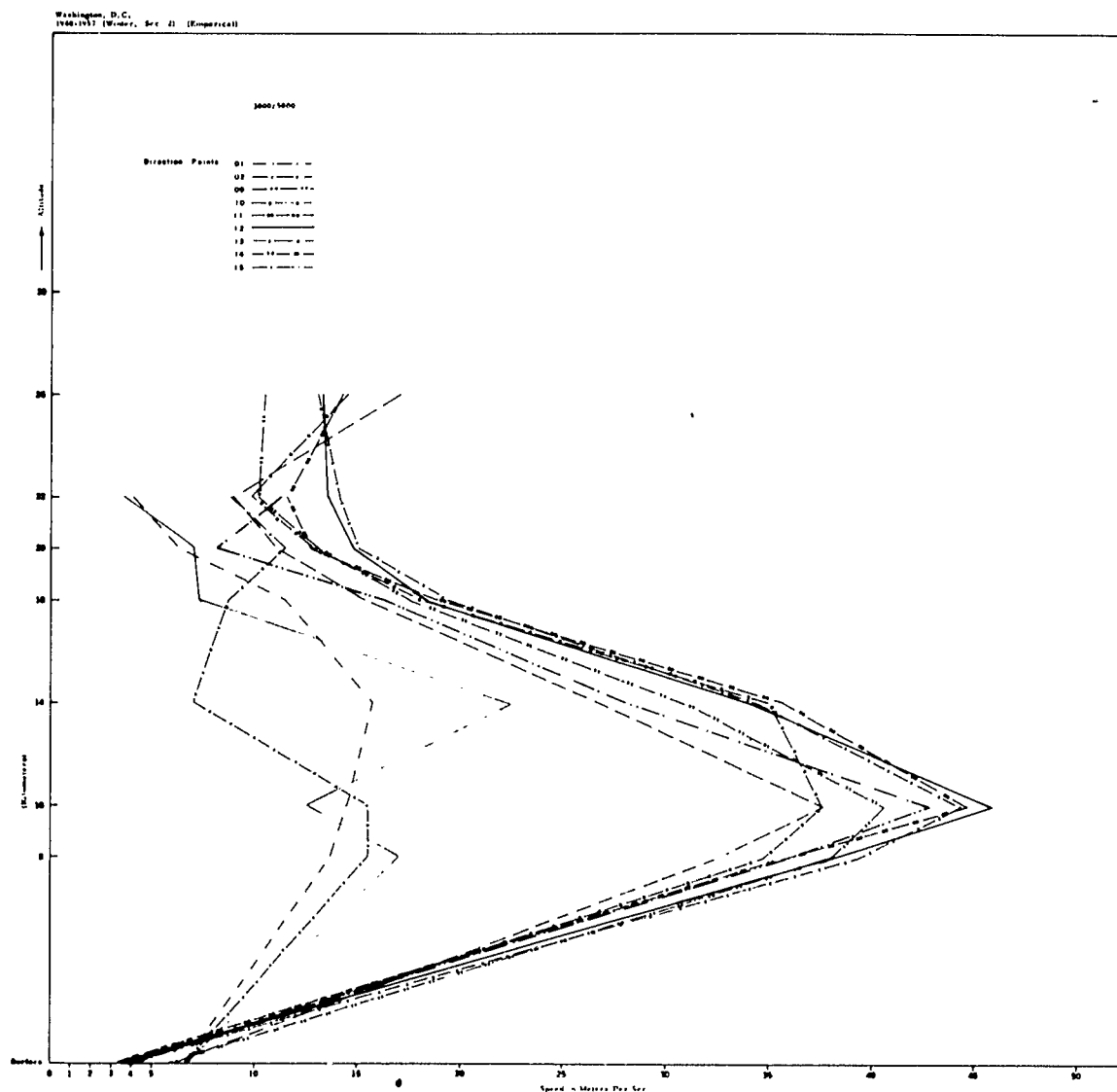


Figure 16 Median speed profiles for weather situations 3000/5000 at Washington, D.C. (Silver Hill) in winter, section 2.

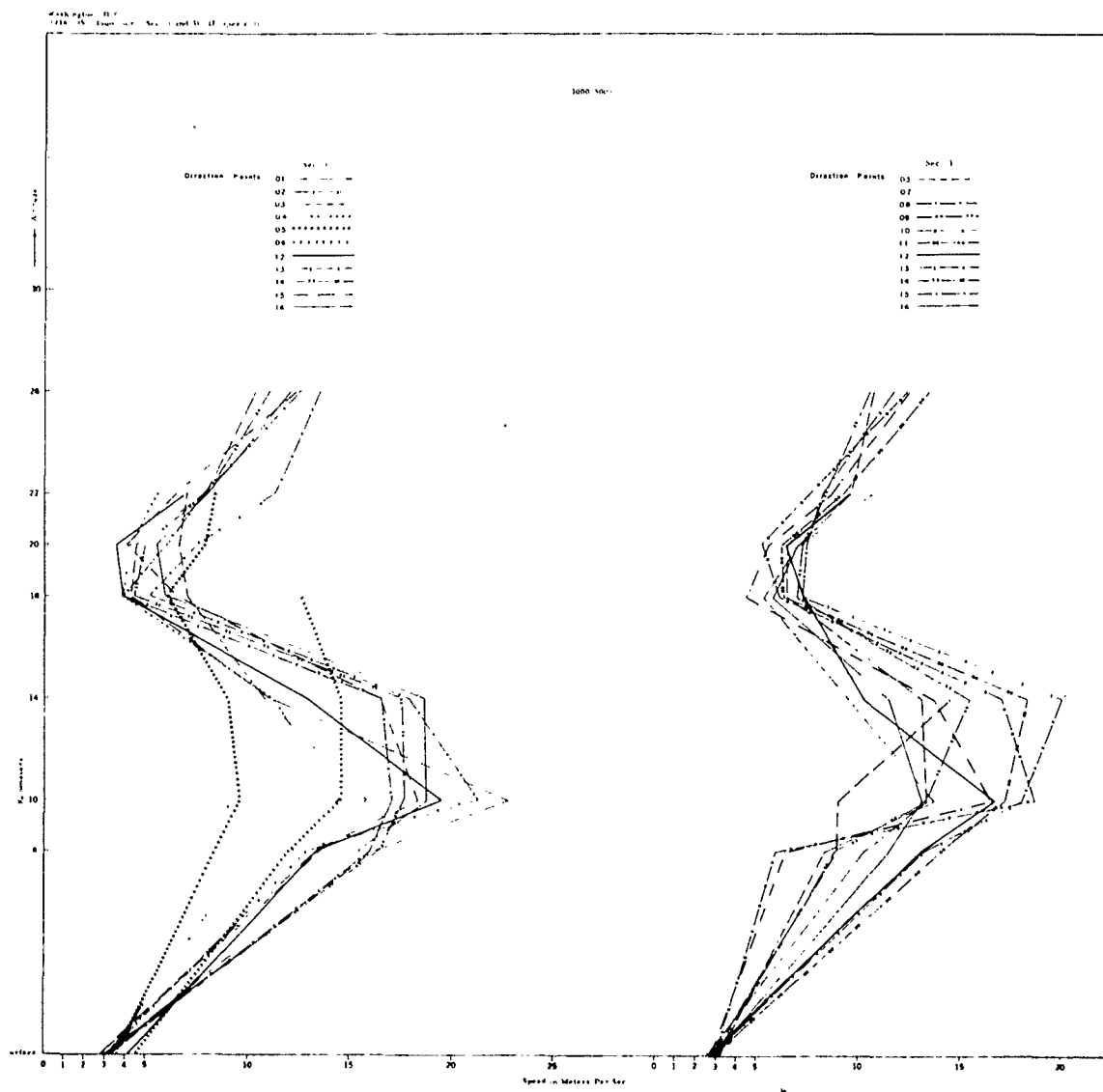


Figure 17 Median speed profiles for weather situations 3000/5000 at Washington, D.C. (Silver Hill) in summer, section 1 and 3.

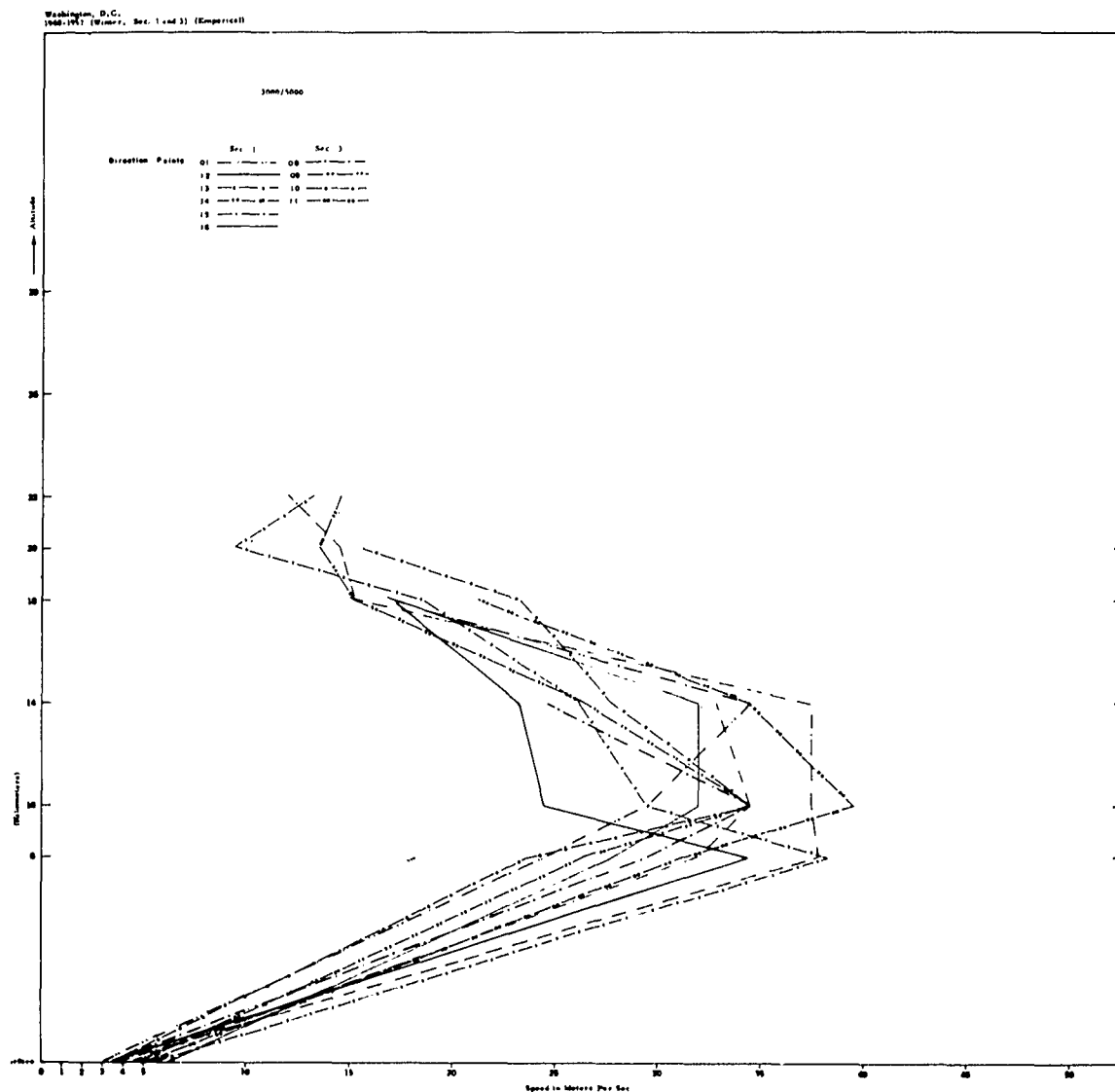


Figure 18 Median speed profiles for weather situations 3000/5000 at Washington, D.C. (Silver Hill) in winter, section 1 and 3.

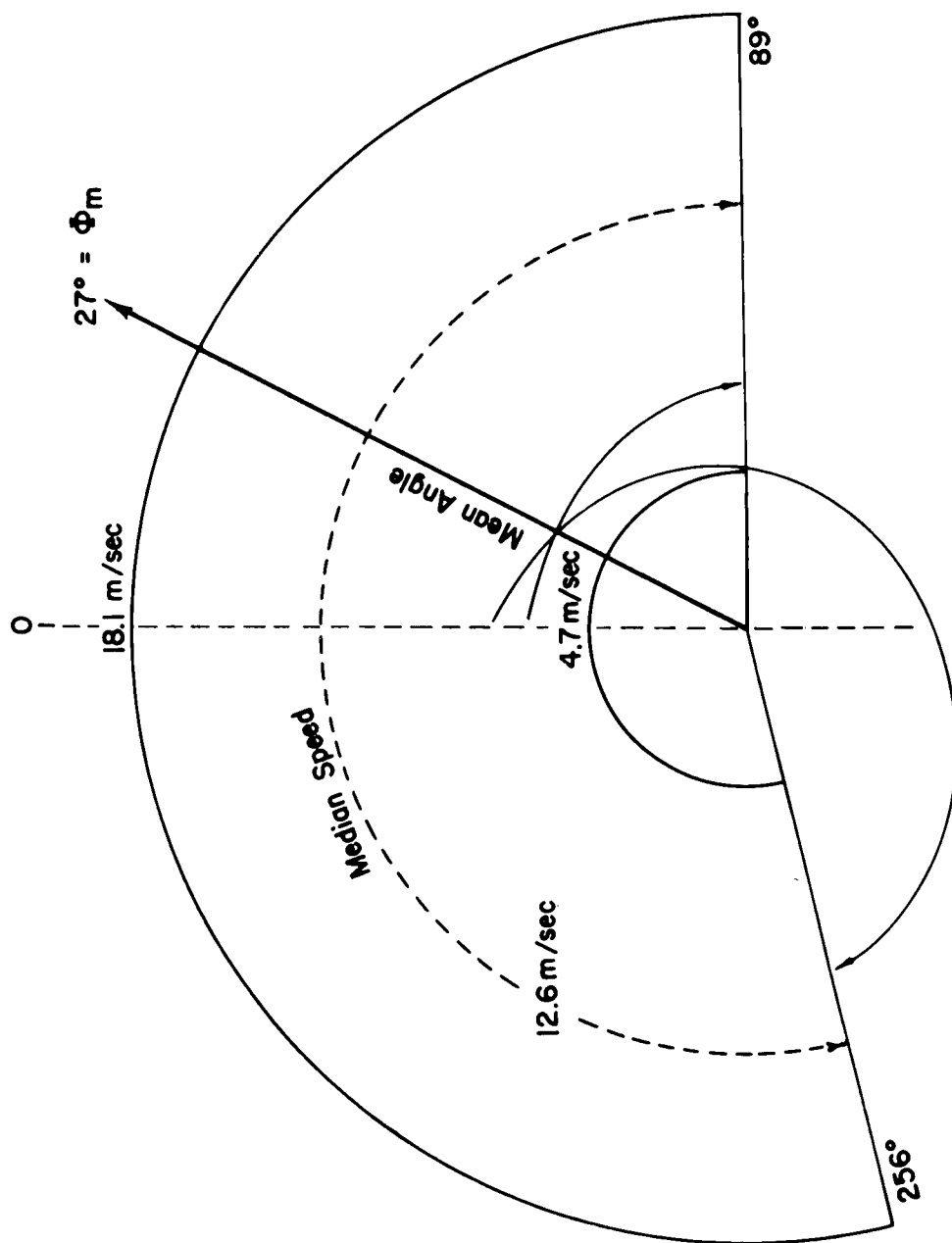


Figure 19 Empirical scatter range $\pm \sigma$ ($= +34$ percent of N) for example in Tables 19 and 20, 8 Km level, section 2.

Table 1

Percentage frequency of local weather situations (classification types)
for Washington, D. C.

January 1948 through December 1957

Classi- fication *)	1500/3000				1500/5000				3000/5000			
	Sec 1	Sec 2	Sec 3	n	Sec 1	Sec 2	Sec 3	n	Sec 1	Sec 2	Sec 3	n
01	50.5	43.9	5.6	337	60.1	33.0	6.9	303	29.9	62.5	7.6	144
02	46.4	45.0	8.6	220	57.0	29.0	14.0	200	31.4	58.8	9.8	102
03	39.9	39.9	20.2	203	46.0	25.7	28.3	187	21.5	53.9	24.6	65
04	34.5	35.7	29.8	168	35.6	23.3	41.1	146	54.3	28.6	17.1	35
05	26.4	35.4	38.2	144	23.2	25.6	51.2	129	34.0	23.4	42.6	47
06	11.9	34.3	53.8	143	17.6	16.0	66.4	125	21.3	38.3	40.4	47
07	11.6	36.6	51.8	164	9.4	22.3	68.3	139	19.0	36.2	44.8	58
08	3.8	38.5	57.7	314	4.8	26.4	68.8	269	4.6	51.7	43.7	87
09	1.9	56.8	41.3	642	2.6	38.8	58.6	567	2.6	66.7	30.7	228
10	3.4	66.9	29.7	1162	1.7	60.1	38.2	967	1.1	85.4	13.5	621
11	4.6	73.5	21.9	1520	2.6	71.2	26.2	1211	1.8	91.6	6.6	1107
12	6.1	84.6	9.3	1792	7.6	83.2	9.2	1452	3.2	94.1	2.7	1513
13	15.4	78.8	5.8	1804	16.5	77.6	5.9	1475	5.6	91.5	2.9	1518
14	25.0	72.0	3.0	1619	33.2	62.8	4.0	1362	11.5	85.3	3.2	1009
15	36.0	61.4	2.6	1118	51.6	44.7	3.7	951	22.0	73.7	4.3	509
16	43.4	51.6	5.0	634	60.3	35.5	4.2	541	29.5	66.4	4.1	244
Total	17.4	67.1	15.5	11984	21.9	58.7	19.4	10024	8.4	84.5	7.1	7334

*) Wind direction in 1500 (or 3000) m as lower level of the classification
in 16 points of the compass.

Table 2

Percentage frequency of local weather situations (classification types) for Washington, D.C. by seasons (1948-1957)

Levels 1500/3000 m

Wind direction 1500 m		Levels 1500/3000 m																			
		Winter						Spring						Summer				Fall			
		Sec 1	Sec 2	Sec 3	n	Sec 1	Sec 2	Sec 3	n	Sec 1	Sec 2	Sec 3	n	Sec 1	Sec 2	Sec 3	n				
01		46.0	54.0		50	42.4	52.5	5.1	59	55.7	35.8	8.5	106	51.6	42.6	5.8	122				
02		44.8	48.3	6.9	29	48.9	40.0	11.1	45	44.7	49.4	5.9	85	47.5	41.0	11.5	61				
03		90.0	5.0	5.0	20	46.7	23.3	30.0	30	47.4	34.6	18.0	78	16.0	61.3	22.7	75				
04		50.0	10.0	40.0	10	38.9	33.3	27.8	18	35.0	33.8	31.2	80	30.0	43.3	26.7	60				
05				100.0	9	5.3	36.8	57.9	19	42.9	30.1	27.0	63	18.9	47.2	33.9	53				
06			31.6	68.4	19	4.3	21.8	73.9	23	26.0	34.0	40.0	50	5.9	41.2	52.9	51				
07			15.4	84.6	26	4.3	34.8	60.9	23	19.6	39.3	41.1	56	11.9	44.1	44.0	59				
08			41.3	58.7	46		34.1	65.9	85	6.7	32.0	61.3	75	6.5	45.4	48.1	108				
09			60.0	40.0	135	2.3	51.7	46.0	174	4.0	45.6	50.4	125	1.4	65.9	32.7	208				
10			84.7	15.3	281	7.2	54.9	37.9	304	3.3	53.0	43.7	270	2.9	74.6	22.5	307				
11	0.9	89.2	9.9	426		8.5	60.8	30.7	388	5.6	61.4	33.0	360	3.8	80.9	15.3	346				
12	5.3	92.8	1.9	528		4.5	87.0	8.5	446	6.1	74.0	19.9	423	8.9	82.3	8.8	395				
13	12.9	86.7	0.4	481		14.5	80.9	4.6	509	14.6	71.3	14.1	425	20.3	74.5	5.2	389				
14	29.5	70.3	0.2	414		19.6	77.9	2.5	393	22.9	71.7	5.4	445	28.1	68.1	3.8	367				
15	37.6	61.6	0.8	250		29.2	69.5	1.3	243	32.8	62.0	5.2	345	44.6	53.2	2.2	280				
16	51.0	48.0	1.0	102		32.6	63.7	3.7	135	37.3	54.4	8.3	217	54.4	41.1	4.5	180				
Total	14.9	76.9	8.2	2826		14.4	67.9	17.7	2894	19.8	59.4	20.8	3203	20.0	65.5	14.5	3061				

Table 3
Percentage frequency of local weather situations (classification types)
for Washington, D. C. by seasons (1948-1957)
Levels 1500/5000 m

Wind direction
hr 1500

Levels 1500/5000 m

	Winter				Spring				Summer				Fall								
	Sec 1		Sec 2		Sec 3		n	Sec 1		Sec 2		Sec 3		n	Sec 1		Sec 2		Sec 3		n
	Sec 1	Sec 2	Sec 3	n	Sec 1	Sec 2		Sec 3	n	Sec 1	Sec 2	Sec 3	n		Sec 1	Sec 2	Sec 3	n			
1	58.3	31.2	10.5	48	50.9	35.8	13.3	53	64.6	32.3	3.1	96	61.3	33.0	5.7	106					
2	50.0	35.7	14.3	28	55.0	37.5	7.5	40	60.5	23.7	15.8	76	57.1	26.8	16.1	56					
3	73.7		26.3	19	56.0	24.0	20.0	25	57.7	22.5	19.8	71	23.6	36.1	40.3	72					
4	37.5	12.5	50.0	8	40.0	13.3	46.7	15	36.2	23.2	40.6	69	33.3	27.8	38.9	54					
5	14.3		85.7	7	5.3	15.8	78.9	19	31.0	31.0	38.0	58	22.2	26.7	51.1	45					
6			100.0	16	4.8		95.2	21	33.0	13.5	41.5	41	10.6	25.5	63.9	47					
7		7.7	92.3	26	5.3	13.3	46.7	19	15.9	25.0	52.1	44	10.0	30.0	60.0	50					
8		17.2	82.8	35	1.3	19.5	79.2	77	12.1	16.7	71.2	66	4.4	42.9	52.7	91					
9	0.8	35.2	64.0	122	1.3	31.6	67.1	155	5.8	34.9	59.3	103	3.2	49.2	47.6	187					
10	0.9	69.9	29.2	226	1.3	49.6	49.1	236	1.7	50.9	47.4	234	2.9	69.0	28.1	271					
11	0.9	84.4	14.7	320	1.5	67.4	31.1	328	3.6	55.2	41.2	277	4.9	76.2	18.9	286					
12	7.1	90.3	2.6	393	5.8	87.6	6.6	362	6.4	74.9	18.7	359	11.5	79.0	9.5	338					
13	13.1	85.8	1.1	381	13.7	83.2	3.1	417	13.8	73.0	13.2	348	27.0	65.7	7.3	329					
14	39.9	59.8	0.3	346	31.2	65.4	3.4	321	24.4	68.1	7.5	386	38.8	56.6	4.6	309					
15	56.9	42.6	0.5	216	41.9	53.9	4.2	191	46.2	46.9	6.9	303	61.4	36.5	2.1	241					
16	79.1	20.9		86	49.1	41.2	9.7	114	53.4	42.9	3.7	191	66.7	30.0	3.3	150					
Total	20.8	66.1	13.1	2277	16.6	61.6	21.8	2393	23.9	53.2	22.9	2722	25.7	55.1	19.2	2632					

Table 4
Percentage frequency of local weather situations (classification types)
for Washington, D.C. by seasons (1948-1957)
Levels 3000/5000 m

Wind direction in 3000 m	Winter			Spring			Summer			Fall		
	Sec 1	Sec 2	Sec 3	n	Sec 1	Sec 2	Sec 3	n	Sec 1	Sec 2	Sec 3	n
01	50.0	50.0		18	10.8	78.4	10.8	37	36.5	57.1	6.4	63
02	15.8	68.4	15.8	19	9.0	86.4	4.6	22	48.6	37.1	14.3	35
03	20.0	40.0	40.0	5	20.0	70.0	10.0	10	34.8	34.8	30.4	23
04					50.0		50.0	4	66.7	26.7	6.6	15
05	25.0		75.0	4	25.0	16.7	58.3	12	45.0	25.0	30.0	20
06		20.0	80.0	5		30.0	70.0	10	33.3	44.4	22.3	18
07		25.0	75.0	4	18.7	12.5	68.8	16	21.7	43.5	34.8	23
08		50.0	50.0	14	5.9	50.0	44.1	34	11.1	55.6	33.3	18
09	3.0	70.1	26.9	67	1.6	57.8	40.6	64	6.8	59.1	34.1	44
10	0.5	92.8	6.7	221	0.5	83.8	15.7	198	2.4	64.6	33.0	82
11	1.3	96.4	2.3	451	1.2	91.8	7.0	341	2.0	83.0	15.0	153
12	2.9	96.0	1.1	552	2.8	94.4	2.8	544	3.4	91.0	5.6	233
13	4.5	94.9	0.6	510	5.0	93.5	1.5	543	7.5	83.0	9.5	294
14	9.0	89.6	1.4	290	10.8	87.2	2.0	306	12.6	80.9	6.5	277
15	21.3	77.5	1.2	89	19.2	77.8	3.0	167	23.4	69.5	7.1	167
16	36.1	63.9		36	27.5	70.3	2.2	91	32.1	59.3	8.6	81
Total	5.2	91.3	3.5	2285	6.5	86.6	6.9	2399	14.1	74.0	11.9	1546
									11.2	80.3	8.5	1104

Table 5

Comparison of resultant wind vector and mean value from wind coordinates
for selected weather situations at Washington, D. C. in winter
(Units: Speed m/sec and direction degrees)

Weather Situation	01				10			
	Resultant Wind Vector		Wind Coordinates		Resultant Wind Vector		Wind Coordinates	
	Speed	Direction	Speed	Direction	Speed	Direction	Speed	Direction
Level								
26 Km	11.9	273°	15.0	262°	14.9	258°	16.6	272°
22 Km	7.7	262°	8.6	265°	10.2	262°	11.7	270°
20 Km	8.2	279°	7.1	290°	10.1	268°	12.0	283°
18 Km	11.0	274°	10.0	291°	18.9	262°	19.4	263°
14 Km	17.7	279°	16.1	254°	34.4	288°	36.7	266°
10 Km	10.8	314°	15.9	4°	35.9	256°	39.7	256°
8 Km	12.6	332°	16.1	16°	29.9	254°	33.1	248°
SFC	6.6	22°	6.0	335°	2.3	175°	2.8	166°

Weather Situation	13				16			
	Resultant Wind Vector		Wind Coordinates		Resultant Wind Vector		Wind Coordinates	
	Speed	Direction	Speed	Direction	Speed	Direction	Speed	Direction
Level								
26 Km	6.7	263°	10.3	280°				
22 Km	9.3	271°	12.1	285°	7.7	277°	8.5	292°
20 Km	12.5	272°	14.4	273°	11.2	271°	11.8	270°
18 Km	16.8	272°	19.2	272°	13.8	272°	14.0	267°
14 Km	30.2	273°	31.7	273°	24.7	281°	24.3	277°
10 Km	42.7	279°	44.0	280°	24.4	289°	27.6	295°
8 Km	37.7	282°	38.7	282°	16.4	296°	24.8	320°
SFC	3.1	277°	4.2	270°	5.4	329°	4.7	330°

Table 6

Comparison of resultant wind vector and mean from wind coordinates
for selected weather situations at Washington, D.C. in summer
(Units: Speed m/sec and direction degrees)

Weather Situation	01			04			07		
	Resultant Wind Vector		Wind Coordinates	Resultant Wind Vector		Wind Coordinates	Resultant Wind Vector		Wind Coordinates
	Speed	Direction	Speed Direction	Speed	Direction	Speed Direction	Speed	Direction	Speed Direction
Level									
26 Km	10.1	96°	9.9 99°	11.3 93°	11.4 86°	9.5 98°	8.9	98°	
24 Km	8.5	90°	9.1 88°	6.1 101°	6.2 97°	4.0 97°	3.5	97°	
22 Km	5.1	75°	4.9 79°	7.9 36°	6.3 43°	2.8 109°	3.5	122°	
18 Km	2.4	25°	4.4 19°	4.6 340°	16.1 304°	10.0 219°	12.7	194°	
14 Km	10.6	307°	13.8 324°	4.6 57°	15.3 88°	15.7 202°	21.6	198°	
12 Km	10.1	325°	20.2 344°	5.6 55°	10.8 27°	14.1 195°	15.1	194°	
8 Km	9.7	343°	14.3 351°	3.5 69°	4.6 68°	1.9 127°	3.0	121°	
SFC	0.9	31°	2.1 15°						

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Weather Situation	10			13			16		
	Resultant Wind Vector		Wind Coordinates	Resultant Wind Vector		Wind Coordinates	Resultant Wind Vector		Wind Coordinates
	Speed	Direction	Speed Direction	Speed	Direction	Speed Direction	Speed	Direction	Speed Direction
Level									
26 Km	10.2	91°	13.1 99°	11.3 88°	11.8 96°	9.4 95°	10.0	99°	
24 Km	11.4	94°	11.0 95°	11.2 94°	11.4 93°	7.3 89°	7.0	98°	
22 Km	7.0	94°	6.8 101°	6.4 92°	6.2 90°	4.5 74°	5.2	74°	
20 Km	4.6	96°	5.2 97°	3.8 94°	4.1 58°	2.8 7°	5.6	344°	
18 Km	0.4	93°	4.9 89°	2.3 304°	4.9 317°	13.3 317°	17.6	295°	
14 Km	13.2	267°	18.9 281°	17.5 280°	21.2 288°	16.8 332°	12.0	333°	
10 Km	15.5	246°	17.6 259°	20.1 281°	22.8 291°	14.2 331°	16.6	329°	
8 Km	13.8	246°	15.0 254°	16.8 284°	18.4 288°	1.2 335°	2.3	321°	
SFC	2.4	185°	2.8 187°	1.4 270°	2.5 265°				

Table 7

Difference between resultant wind vector and wind coordinates from
Tables 5 and 6 (wind coordinates minus res. wind vector)
(Units: Speed m/sec and direction degrees)

Winter

Speed					Direction			
Weather Situation	01	10	13	16	01	10	13	16
Level								
26 Km	3.1	1.7	3.6		-11°	14°	17°	
22 Km	0.9	1.5	2.8	0.8	3°	8°	14°	15°
20 Km	-1.1	1.9	1.9	0.6	11°	15°	1°	-1°
18 Km	-1.0	0.5	2.4	0.2	17°	1°	0°	-5°
14 Km	-1.6	2.3	1.5	-0.4	-25°	-22°	0°	-4°
10 Km	5.1	3.8	1.3	3.2	50°	0°	1°	6°
8 Km	3.5	3.2	1.0	8.4	44°	-6°	0°	24°
SFC	-0.6	0.5	1.1	-0.7	-47°	-9°	-7°	1°

Summer

Speed							Direction					
Weather Situation	01	04	07	10	13	16	01	04	07	10	13	16
Level												
30 Km				2.9	0.5					8°	8°	
26 Km	-0.2			-0.4	0.2	0.6	3°			1°	-1°	4°
22 Km	0.6	0.1	-0.6	-0.2	-0.4	-0.3	-2°	-7°	0°	7°	-2°	-1°
20 Km	-0.2	0.1	-0.5	0.6	0.3	0.7	4°	-4°	0°	1°	-36°	0°
18 Km	2.0	-1.6	0.7	4.5	1.6	2.8	-6°	7°	13°	-4°	13°	-23°
14 Km	3.2	11.5	2.7	5.7	3.7	4.3	17°	-36°	-25°	14°	8°	-32°
10 Km	10.1	10.7	5.9	1.1	2.7	-4.8	15°	31°	-4°	13°	10°	1°
8 Km	4.6	5.2	1.0	1.2	1.6	2.4	8°	-28°	-1°	8°	4°	-2°
SFC	1.2	1.1	1.1	0.4	1.1	1.1	-16°	-1°	-6°	2°	-5°	-14°

Table 8

Mean wind direction in degrees by weather situation 1500/3000 m
for Washington, D. C.

Winter, Sec. 2

Level	Total data of Section 2	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16
30 Km	268									310	272	274	292	280	344	302	
26 Km	304	262								291	270	277	273	285	303	313	293
22 Km	278	265	313							274	283	279	282	273	279	298	270
20 Km	280	290	323						252	263	263	270	268	273	275	279	267
18 Km	276	291	317						245	252	266	269	271	273	276	276	277
14 Km	274	254	334						259	244	256	265	284	280	284	292	295
10 Km	276	4	34						246	234	248	260	270	282	288	301	320
8 Km	278	16	32						233	202	225	247	270	292	315	337	360
Entrance	---	22	45						180	172	166	192	240	270	300	315	329
SFC	257	335	360						115								

Table 9
Mean wind direction in degrees by weather situation 1500/3000 m
for Washington, D. C.

Summer, Sec. 2

Total data of																	
Level	Section 2	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16
30 Km	90										99		97	96	86	88	
26 Km	92	99	97	90			90		94	90	95	92	91	93	91	83	99
22 Km	91	88	97	88	86	93	92	98	96	85	101	93	97	90	87	83	88
20 Km	82	79	96	88	97	85	79	97	97	76	97	82	101	58	77	71	74
18 Km	349	19	90	94	43	80	45	122	26	9	89	332	306	317	12	353	344
14 Km	295	324	303	331	304	220	176	194	205	277	281	291	283	286	300	306	295
10 Km	288	344	294	329	88	180	176	198	207	269	259	275	279	291	299	304	333
8 Km	290	351	346	33	27	174	162	194	191	253	254	260	268	288	302	308	329
Entrance	298	22	45	68	90	112	135	158	180	202	225	248	270	292	315	338	360
SFC	255	15	43	83	68	86	95	121	140	182	187	196	233	265	304	311	321

Table 9
Mean wind direction in degrees by weather situation 1500/3000 m
for Washington, D. C.

Summer, Sec. 2

Total data of																	
Level	Section 2	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16
30 Km	90	99	97	90			90		94	90	95	92	91	93	96	86	88
26 Km	92	88	97	88	86	93	92	98	96	85	101	93	97	90	87	83	99
22 Km	91	79	96	88	97	85	79	97	97	76	97	82	101	58	77	71	88
20 Km	82	19	90	94	43	80	45	122	26	9	89	332	306	317	12	353	344
18 Km	349	324	303	331	304	220	176	194	205	277	281	291	283	286	300	306	295
14 Km	295	344	294	329	88	180	176	198	207	269	259	275	279	291	299	304	333
10 Km	288	351	346	33	27	174	162	194	191	253	254	266	268	288	302	308	329
8 Km	290	22	45	68	90	112	135	158	180	202	225	248	270	292	315	338	360
Entrance	298	15	43	83	68	86	95	121	140	182	187	196	233	265	304	311	321
SFC	255																

Table 10
Standard deviation in degrees by weather situation 1500/3000 m
for Washington, D. C.

Winter, Sec. 2

Total Data of		Adjusted*)																	
Level	Section 2	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	Average	Average
30 Km	42									59	63	82	76	82	86	56		30	27
26 Km	76	21								62	49	70	60	69	70	72		66	56
22 Km	66	39	60						69	48	50	52	57	44	51	70	52	61	
20 Km	52	32	39						50	41	21	28	34	32	27	34	32	48	
18 Km	32	37	56						34	25	20	18	19	23	20	22	18	33	
14 Km	26	69	55						20	25	25	24	30	24	26	24	43	28	
10 Km	34	75	85						25	30	23	25	21	25	28	28	63	37	
8 Km	35	77	63						23	28	23	25	21	25	28	28	63	36	
SFC	84	14	30						33	94	62	77	77	67	43	28	25	46	
Mean	50	46	55						36	48	39	47	45	46	44	42	32		
Adj. Mean*)		44	50						36	46	37	45	45	44	42	40	36		

*) The adjusted values have been computed under consideration which value would be expected if the columns (lines) were filled in. This makes the column (line) average comparable.

Table 11

Standard deviation in degrees by weather situation 1500/3000 m
for Washington, D. C.

Summer, Sec. 2

Total Data of		Adjusted*)																	
Level	Section 2	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	Average	Average
30 Km	32	19	23	12			18		9	19	14	27	16	27	44	16	18	26	28
26 Km	25	38	29	22	15	14	19	14	21	25	29	29	38	36	20	33	34	20	20
22 Km	32	50	46	27	32	18	41	25	24	41	47	64	70	92	31	31	26	26	
20 Km	59	73	81	75	58	62	73	70	84	91	103	91	86	75	59	58	56	47	
18 Km	86	59	79	72	75	76	94	51	89	60	53	54	39	43	37	43	46	61	
14 Km	51	72	80	72	97	74	90	52	67	74	50	49	33	41	40	47	44	61	
10 Km	54	68	82	75	79	79	95	35	59	56	35	38	31	35	34	39	43	55	
8 Km	52	88	71	51	48	51	45	69	50	57	58	62	66	70	75	66	79	63	
SFC	86																		
Mean	53	58	61	51	58	53	59	45	50	53	47	52	45	51	43	46	50		
Adj. Mean*)		55	58	48	51	47	56	41	48	50	47	49	45	51	43	46	48		

*) See footnote to table 10.

Table 12

Mean wind direction in degrees by weather situation 3000/5000 m
for Washington, D. C.

Winter, Sec. 2

Level	Total data of																	
	Section 2		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16
30 Km	268												251	266	281			
26 Km	305										337	261	256	306	317	329	290	288
22 Km	278		270	292							312	274	276	264	257	288	294	259
20 Km	276		285	320							248	274	282	274	265	271	276	292
18 Km	269		285	324							232	260	263	264	276	276	276	262
14 Km	271		308	349						234	243	254	264	270	277	296	283	277
10 Km	268		358	55						214	231	244	257	271	283	293	304	307
8 Km	272		22	64						210	222	235	254	270	284	300	316	321
Entrance	---		22	45						180	202	225	248	270	292	315	338	360
SFC	261		338	344						68	87	191	191	252	268	299	323	327

Table 13

Mean wind direction in degrees by weather situation 3000/5000 m
for Washington, D. C.

Summer, Sec. 2

Total data of																	
Level	Section 2	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16
30 Km	92											108	93	82	114	83	
26 Km	93	92	88					96		90	94	94	94	91	87	90	90
22 Km	89	83	102	84			101	88	97	98	99	95	98	88	85	82	82
20 Km	82	95	79	59			80	83	92	92	93	101	101	81	72	44	68
18 Km	343	54	35	31		112	90	149	164	167	143	246	267	321	352	2	26
14 Km	294	344	333	5	278	217	211	192	197	259	263	277	280	289	307	313	336
10 Km	287	10	338	346	155	166	188	193	166	244	255	262	276	288	306	311	340
8 Km	288	11	25	22	108	155	182	186	177	234	242	278	273	289	306	319	345
Entrance	---	22	45	68	90	112	135	158	180	202	225	248	270	292	317	338	360
SFC	257	314	89	97	85	59	94	115	95	166	187	232	238	277	284	280	299

Table 14

Standard deviation in degrees by weather situation 3000/5000 m
for Washington, D. C.

Winter, Sec. 2

Total Data of		Adjusted*) Average																
Level	Section 2	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	Average
30 Km	51										63	9	16					29
25 Km	77									58	58	73	76	80	82	55	44	65
22 Km	66	42	14							65	56	65	56	77	64	66	32	54
20 Km	51	33	47							58	43	58	45	51	57	44	33	47
18 Km	32	36	40							34	29	25	31	33	31	24	22	30
14 Km	24	72	64						20	19	22	19	17	20	22	21	19	29
10 Km	33	58	34						16	24	25	24	20	21	20	22	50	29
8 Km	36	46	32						13	6	22	44	20	21	21	24	72	29
SFC	85	28	26						38	76	86	87	83	77	46	40	31	56
Mean	51	45	47						22	42	43	51	40	44	43	37	38	
Adj. Mean*)		42	31						23	40	40	51	40	44	41	35	36	

*) The adjusted values have been computed under consideration, which value would be expected, if the columns (lines) were filled in. This makes the column (line) average comparable.

Table 15

Standard Deviation in degrees by weather situation 3000/5000 m
for Washington, D. C.

Summer, Sec. 2

Total Data of		Summer, Sec. 2																Adjusted*)	
Level	Section 2	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	Average	Average
30 Km	25											27	31	22	15	18		23	19
26 Km	24	24	15					20		12	18	23	27	20	27	28	16	21	16
22 Km	33	28	42	22			16	19	19	32	31	36	40	34	32	27	27	29	28
20 Km	60	60	55	29			15	24	31	43	49	68	68	66	54	44	45	46	42
18 Km	84	71	68	46		48	32	69	91	94	95	90	82	73	65	68	63	70	70
14 Km	49	56	83	58	64	82	72	72	73	55	49	53	39	29	37	38	36	56	
10 Km	51	58	80	86	95	51	69	70	53	60	42	38	36	30	36	45	41	56	
8 Km	48	57	61	44	79	61	67	49	30	46	32	31	29	26	30	32	33	44	
SFC	91	96	70	87	56	66	52	62	69	67	72	82	81	85	84	86	94	76	
Mean	52	63	59	53	74	62	46	48	52	51	48	50	48	43	42	43	44		
Adj. Mean*)		58	55	45	49	42	39	44	45	47	45	50	48	43	42	43	41		

*) See footnote Table 14

Table 16

Difference between standard deviation for weather situation 1500/3000 m (symbol σ_{15}) and standard deviation for weather situation 3000/5000 m (symbol σ_{30})

$$\Delta\sigma = \sigma_{15} - \sigma_{30} \quad (\text{in degrees})$$

A) Winter, Section 2

Level	Total data of Section 2															Average (Adj.)
	01	02	08	09	10	11	12	13	14	15	16					
30 Km		-9					21								6	
26 Km		-1			5	9	0	2	4						0	
22 Km		0	36	-3	-7	5	4	-8		1	20				10	
20 Km	-3		-8	-10	7	-6	12	-7		6	-1				2	
18 Km	-1	16			8	3	3	-1		36	1				3	
14 Km	1		0	7	-2	-1	2		4	10	-1				-1	
10 Km	-3	-9		6		0	10	3	6	1	-7				8	
8 Km	17	51	9	6	0	0	1	3	7	2	-9				7	
10 Km	31	31	10	22	1	-19	1	4		4	-6				-10	
SFC	-14	4	-5	18	-24	-10	-6	-10	-3	-12						

B) Summer, Section 2

Total data of		(Adj.)																
Level	Section 2	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	Average
30 Km	7	-5	8				3	-5	2	7	-4	4	-4	22	1	0		9
26 Km	1	10	-13				26	1	-7	-7	-2	-7	-11	2	-7	5	18	4
22 Km	-1	-10	-9	0						-2	-2	-4	-2	2	-1	4	-1	-2
20 Km	-1		-2	-2			41	1	16	-3	8	1	4		5	14	11	5
18 Km	2	-2	13	29		14	22	-21	14	14	4	1	0	2	7	9	13	8
14 Km	2	3	-4	24		-6	22	-18	14	5	8	11	-3	11	4	5	10	5
10 Km	3	14	0	2	11	23	21	-14	29	10	3	7	2	9	4	2	3	5
8 Km	4	11	21	31	0	18	28	-14	10	10	3	7	2	9	4	7	10	11
SFC	-5	-8	1	-36	-8	-15	-7	7	-19	-10	-14	-20	-15	-15	-9	-20	-15	-13

Departure from Entrance Level in Turn Angles, Positive in a Turn to the Right (Clockwise).

71

Absolute Departures from $\phi_{\text{m}}(\phi_{\text{m}}$ in Wind Coordinates, $N=360$, $E=90$, $S=180$, $W=270$).

72

Actual Wind Coordinates (N=360, E=90, S=180, W=270)

73

Table 20

Empirical distribution of scalar wind speed (meters/sec)
for Washington, D.C. (Silver Hill) in summer (June, July, August)
for weather situation East (04)

Section 1

Level	Max. Value	2.28	15.9	50.0	84.1	97.72	n
30 Km							
26 Km	19	5.0	8.5	13.3	17.5	19.3	10
22 Km	19	1.7	5.2	7.9	14.3	18.8	13
20 Km	19	1.7	4.9	7.3	11.0	18.0	13
18 Km	19	1.1	4.6	7.3	12.5	18.5	14
14 Km	49	6.0	11.3	19.5	30.5	46.5	15
10 Km	49	5.3	9.3	17.5	27.3	36.5	16
8 Km	29	1.7	6.8	13.8	20.0	28.0	16
SFC	9	0.6	1.4	3.2	6.4	9.1	25

Section 2

Level	Max. Value	2.28	15.9	50.0	84.1	97.72	n
30 Km							
26 Km							
22 Km	19	4.8	6.8	12.0	17.2	19.2	9
20 Km	19	1.3	4.8	7.0	9.2	17.5	10
18 Km	19	0.9	3.1	7.0	13.0	18.5	10
14 Km	49	1.1	5.0	18.3	29.3	46.5	15
10 Km	39	1.7	10.9	15.9	25.8	36.5	16
8 Km	29	1.1	4.7	12.6	18.1	26.5	16
SFC	19	0.7	2.1	5.4	9.1	17.5	21

Section 3

Level	Max. Value	2.28	15.9	50.0	84.1	97.72	n
30 Km							
26 Km							
22 Km	19	4.6	5.6	8.1	14.2	18.8	11
20 Km	19	0.7	2.1	5.7	11.5	18.5	12
18 Km	19	0.7	2.2	6.0	11.0	18.0	13
14 Km	29	4.9	7.3	15.5	25.1	28.9	15
10 Km	49	1.7	9.8	21.6	27.9	46.5	17
8 Km	39	1.3	7.6	12.0	18.9	35.5	18
SFC	9	0.6	1.5	3.6	7.3	9.2	22

Table 21

Percentage frequency of cases in which significant departure between theoretical and empirical σ -range exists.

(More details in text).

A) Winter

Level	Threshold value in % of frequency distribution (range)						Average	Number of distributions
	2.28	15.9	32.0	68.0	84.1	97.72%		
30 Km	0	0	0	0	0	0	--	1
26 Km	45	37	18	64	46	18	38	11
22 Km	60	53	47	40	40	40	47	15
20 Km	44	38	44	19	44	12	33	16
18 Km	27	21	27	27	5	37	24	19
14 Km	10	10	10	10	5	19	10	21
10 Km	5	10	5	0	5	5	5	21
8 Km	14	14	5	0	5	14	9	21
SFC	33%	29	19	38	29	48	33%	21
Sum	27	24	20	21	19	24	22%	146

B) Summer

Level	Threshold value in % of frequency distribution (range)						Average	Number of distributions
	2.28	15.9	32.0	68.0	84.1	97.72%		
30 Km	--	14	--	--	14	14	7	7
26 Km	12	17	17	17	17	12	15	24
22 Km	33	17	20	20	27	33	25	30
20 Km	27	20	10	20	33	27	24	30
18 Km	10	7	3	0	17	10	8	30
14 Km	17	7	7	10	7	23	12	30
10 Km	20	7	13	10	10	17	13	30
8 Km	23	13	7	0	7	20	12	30
SFC	23	33	23	20	27	30	27	30
Sum	22	15	12	12	18	22	17	241

Table 22

Frequency distribution (in percent) of departures between median and the mean of squared wind speed and between empirical 95% value and theoretical in square scale of wind speeds

Departure in m/sec	Mean-Median		95% frequency	
	Winter	Summer	Winter	Summer
< -10.0			10.4	1.6
-10.0 to -8.1			4.7	1.6
- 8.0 to -6.1			8.1	2.3
- 6.0 to -4.1			9.3	4.6
- 4.0 to -2.1	7.0	1.6	17.4	25.6
- 2.0 to -0.1	50.0	76.7	18.6	26.3
0.0 to 1.9	39.5	21.7	14.0	17.8
2.0 to 3.9	3.5		7.0	13.2
4.0 to 5.9			7.0	4.6
6.0 to 7.9			0	1.6
8.0 to 9.9			0	0.8
≥ 10.0			3.5	
n	86	129	86	129

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